beginnings of the disc ... ics, biology, medicine, astr ... ress was made in two cen ... and enquiry.

The story, here broken off at the death of Aristotle, is continued in the author's second volume (Pelican A192), dealing with the later developments of the Alexandrian age.

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GREEK SCIENCE

BY BENJAMIN FARRINGTON

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GREEK SCIENCE

ITS MEANING FOR US

BY

BENJAMIN FARRINGTON

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VOLUME ONE:

THALES TO ARISTOTLE

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To my friend

DR MIGNON B. ALEXANDER

CONTENTS

FOREWORD

The subject of this book is the earliest period of Greek science – that is, the science of the sixth and fifth centuries B.C.

In many ways the outlook of this period is closer to our own than that of the later periods, whether the great fourth-century movement in Athens that centres round the names of Socrates, Plato, and Aristotle, or the Alexandrian period which begins with men like Euclid and Archimedes and ends with Ptolemy and Galen.

The science of the earliest Greek period resembles ours, for, naïve and undeveloped as it was, it regarded man as a product of natural evolution, it regarded his powers of speech and thought as a product of his life in society, and it regarded his science as part of his technique of the control of his natural environment. These bold ideas made their first appearance among the Ionian Greeks shortly after 600 B.C., and were developed in the course of a couple of centuries with a comprehensiveness of view and an organic cohesion of design which still astonish us to-day. The emergence of this mode of thought and its supersession by the more sophisticated but less scientific outlook of the age of Socrates, Plato and Aristotle are the special subject of our enquiry.

By closing his account with Aristotle the writer has deprived himself of the pleasure of describing the great achievements in particular branches of science of the Alexandrian age, achievements which played so great a rôle in the revival of thought at the Renaissance. But the problems raised by this later development of Greek science are so different that they may well demand separate treatment.

B. F.

ACKNOWLEDGMENT

Mr R. W. Moore, head master of Harrow, read my typescript and made many suggestions which I was glad to adopt. My opinions, like my errors, are my own. But the former would have been more obscurely expressed and the latter more numerous without his help. The reader and I owe him a debt.

B. F.

CHIEF PERIODS AND SCHOOLS

1. *Greek Colonies in Asia*

School of Miletus (Thales, Anaximander, Anaximenes) *c.* 600–550 B.C.

Heraclitus of Ephesus, *floruit c.* 500 B.C.

Hippocratic School of Medicine, centred in island of Cos. (Hippocrates is supposed to have lived from 460 to 380 B.C.)

The early period of Greek thought down to Socrates is often loosely referred to as Ionian because it started in the Ionian colony of Miletus and flourished in such Ionian centres as Ephesus and Cos.

2. *Greek Colonies in Italy and Sicily (Magna Graecia)*

Pythagoras of Croton, *fl. c.* 540.

Parmenides of Elea, *fl. c.* 500.

Empedocles of Akragas, *fl. c.* 450.

3. *Mainland of Greece*

Anaxagoras of Clazomenae in Ionia (*c.* 500–428) settled in Athens under Pericles.

Democritus of Abdera, *fl. c.* 420.

4. *Athens*

Socrates (469–399), Plato (427–367), Aristotle (384–322).

5. *Alexandrian Age*

Mathematicians: Euclid (*fl. c.* 300), Archimedes (287–212), Apollonius (*fl. c.* 220).

Astronomers: Aristarchus (*c.* 310–230), Eratosthenes (*c.* 273–192), Hipparchus (*fl. c.* 125).

Anatomists: Herophilus and Erasistratus (*fl. c.* 290).
Grammarian: Dionysius Thrax (*fl. c.* 130).

6. *Graeco-Roman Period*

Of the Greek thinkers of this time the two best known were the astronomer and geographer, Ptolemy (*fl. c.* A.D. 150) and the anatomist and physician, Galen (A.D. 129–199).

The period from Thales to Democritus is sometimes called the Heroic Age of Science. It is the special subject of this book. The chief difficulty in studying it is that, except for some treatises of the Hippocratic school, only fragmentary records of the work of these early thinkers survive. The works of Plato and Aristotle are studied here chiefly in order to make clear the nature of the revolution in thought inaugurated by Socrates. Only occasional reference is made to scientists of the Alexandrian and Graeco-Roman periods.

CHAPTER ONE

The Background of Greek Science – Science in Pre-Historical Times – The Neolithic Revolution – The Science of the Ancient Civilizations of the Near East

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GREEK science, like Greek civilization as a whole, was deeply indebted to the older civilizations of Egypt and Mesopotamia. But Greek science also struck out new paths for itself. What did it borrow and what did it create? In this chapter we shall examine the contribution of the pre-Hellenic civilizations to science in order to assess as fairly as we can the degree of originality of the Greeks.

'Compared with the empirical and fragmentary knowledge which the peoples of the East had laboriously gathered together during long centuries, Greek science constitutes a veritable miracle. Here the human mind for the first time conceived of the possibility of establishing a limited number of principles, and of deducing from these a number of truths which are their rigorous consequence.' These are the words of a very competent French historian of science, Arnold Reymond.* If we accept his view that science is a logically coherent body of knowledge deduced from a limited number of principles, we can agree that the Greeks were the creators of this ideal, and allow that in several of their sciences they carried it to a very high degree of perfection.

But it is also necessary to regard science from its more prac-

*His book (*Science in Greco-Roman Antiquity*, Methuen, 1927) would have won even greater success in England if it had been adequately translated.

tical side. A recent writer (J. G. Crowther, *Social Relations of Science*) defines science as 'the system of behaviour by which man acquires mastery of his environment'. From this point of view the originality of the Greeks is less striking. In the arts by which man acquires mastery of his environment they were the pupils of the older civilizations. They belonged, however, not to the bronze age but to the iron age, and their success in exploiting the new metal has recently been noted by Gordon Childe. He shows that before 500 B.C. the Greeks by their invention of new iron tools had made a decisive improvement in man's control over nature.* This technical advance coincides in time with the first age, the Heroic Age, of Greek science. It is the contention of this book that the technical and scientific movements are closely connected.

Science, whatever be its ultimate developments, has its origin in techniques, in arts and crafts, in the various activities by which man keeps soul and body together. Its source is experience, its aims practical, its only test that it works. Science arises in contact with things, it is dependent on the evidence of the senses, and however far it seems to move from them, must always come back to them. It requires logic and the elaboration of theory, but its strictest logic and choicest theory must be proved in practice. Science in the practical sense is the necessary basis for abstract and speculative science.

As thus conceived, science develops in close correspondence with the stages of man's social progress and becomes progressively more self-conscious as man's whole way of life becomes more purposive. A food-gatherer has one kind of knowledge of his environment, a food-producer another. The latter is more active and purposive in his relation to mother earth. Increased mastery of the environment brings increased productivity, which, in its turn, brings social change. The

* *Progress and Archaeology* (Watts, Thinker's Library), p. 40.

science of gentile or tribal society cannot be the same as the science of political society. The division of labour has an influence on the development of science. The emergence of a leisured class gives opportunity for reflection and elaboration of theory. It also gives opportunity for theorizing without relation to facts. Furthermore, with the development of classes, the need for a new kind of 'science' arises which might be defined as 'the system of behaviour by which man acquires mastery over man'. When the task of mastering men becomes the preoccupation of the ruling class and the task of mastering nature becomes the forced labour of another class, science takes a new and dangerous turn. Fully to understand the science of any society, we must be acquainted with the degree of its material advancement and with its political structure. There is no such thing as science *in vacuo*. There is only the science of a particular society at a particular place and time. The history of science can only be understood as a function of the total life of society. Hence, in order that we may get an historical understanding of Greek science, we must understand something of the previous evolution of society from the point of view of technical development and political structure, which is the purpose of this chapter.

Man has been on earth, we are told by the best modern authorities, for about five hundred thousand years. He has been civilized for only about one hundredth of that period. To put the point in another way, for about five hundred thousand years there has been on earth a creature who could talk and who had control of fire. It is only about five or six thousand years since there has been on earth a creature who could write and who could call on the police to protect him if someone stole his fuel.

Before writing, before writs, was there anything that could be called science? If we are prepared to accept the definition

of science as the system of behaviour by which man acquires mastery of his environment, there certainly was.

The earliest surviving implements used by man to master his environment are stone tools. From these experts draw proof of the intellectual capacity and slow progress of man even in the Old Stone Age. The growth of manual skill, itself a form of intelligence, is shown in the improved working of the implements. Intellectual advance is shown in the growing ability to discriminate between different kinds of stone. Evidence of increasing purpose and foresight is not lacking. Men mined for flints before they mined for metals. At one stage of his advance man does no more than select suitable stones for his purpose, and trim them. At a later stage he knocks off from a central core flakes of a desired shape and size. It is a revolution in technique. Then his tools are made for increasingly specialized purposes; he has scrapers, points, and chipping tools. He even has tools for making tools, and tools for making tools for making tools. Nor was stone the only material that he used. Knowledge of materials is a very important part of science. The early tool-maker was aware of the advantages for specific purposes of materials other than stone. Wood, bone, antler, ivory, amber, shells provide him with new tools, and witness to us of his growing knowledge.

Nor is his knowledge only of materials. His growing appreciation of mechanical principles is also evident. He early senses the usefulness of the wedge. He makes a further advance when he combines in one tool the functions of the wedge and the lever. The spear-thrower, the bow and arrow, the bow-drill, are all so many landmarks in his progress in mechanics, although, of course, his appreciation of the principles involved is at first practical, sensuous, merged in the operations, untheoretical. But this practical knowledge is the necessary basis of theory. Of Napoleon's great engineer Conté it was said

that he had all the sciences in his head and all the arts in his hands. And even that does not quite strike the nail on the head. 'As a physiologist,' writes J. B. S. Haldane, 'I note that it needs as large an area of brain to control my hands as my vocal organs. And as a scientific worker I note that some of my colleagues appear to do most of their thinking with their hands, and are extremely inexpert at the use of words.' Possibly primitive man talked a great deal of nonsense. There is plenty of evidence that he acted a great deal of sense.

The existence of science before civilization is evident, of course, also in the behaviour of contemporary savages. An excellent observer, Driberg, assures us that savages are reasonable beings capable of inference, logical thought, argument, and speculation. 'There are savage thinkers and philosophers, seers, leaders, and inventors.' Driberg is particularly emphatic on the truly scientific character of some of the activities of the savage. 'Not only does the savage adapt himself to his natural surroundings, he also adapts his natural surroundings to his own needs. It is this unending battle between the forces of nature and human ingenuity which eventually leads to some form of civilization.' To give examples – savages have elaborate devices for securing pure drinking-water; they practise irrigation; afforestation is undertaken for a multiplicity of objects – to restore the soil, to provide protection from the wind, for strategic reasons, for material for spear-shafts, to provide bark for cloth; rivers are stocked; game is preserved. Out of centuries, out of millennia, of such activities spring the arts and crafts on which civilization is based.

The actual origin of civilization depended on the simultaneous mastery or possession of a number of techniques, some new, some old, which, taken together, sufficed to turn man from being mainly a food-gatherer into being mainly a

producer of food. A permanent surplus of food is the necessary basis for the emergence of civil society. Then greater concentrations of population became possible, urban life began, and the neolithic village was overshadowed by the mighty town. The fundamental techniques were the domestication of animals, agriculture, horticulture, pottery, brick-making, spinning, weaving, and metallurgy. These ways of imitating and co-operating with nature constitute a revolution in man's science and a revolution in his way of life. The first area where civilizations based on the combination of these techniques came into existence was in the Near East in the river valleys of the Nile, the Euphrates, and the Indus. The vital period in which the new techniques were developed is roughly the two millennia from 6000 to 4000 B.C.

When history is really taught as it ought to be taught, so that everybody is made to understand, as the foundation of his intellectual life, the true story of human society, one of the most fundamental lessons will be the concrete and detailed exposition of the nature of this great revolution in man's control over his environment. The film, the museum, the workshop, the lecture, the library will combine to make the significance of these vital two thousand years sink into the historical consciousness of mankind. This technical revolution constitutes the material basis of ancient civilization. No comparable change in human destinies took place between it and the industrial revolution of the eighteenth century. The cultures of the ancient empires of the Near East, of Greece and Rome, and of Mediæval Europe, all rest on the technical achievements of the neolithic age. Their resemblances to one another result from this fact. Their differences from us to-day can only be understood when we realize that we are separated from them all by the second great technical revolution, the coming of the Machine Age. Nothing short of a compre-

hensive reform of our system of education would suffice to do justice to the significance of these truths. Meanwhile two books may be brought to the notice of those who wish to understand the rôle of techniques in ancient society. Gordon Childe (*Man Makes Himself*, Watts) has given a brilliant account of the technical revolution of the New Stone Age and the consequent rise of urban life.* Partington's *Origins and Development of Applied Chemistry* (Longmans, Green & Co.) gives an exhaustive and up-to-date summary of man's knowledge of materials from the dawn of civilization down to 1500 B.C. – that is to say, to the end of the Bronze Age. There were, he assures us, very few further developments of applied chemistry between the end of the Bronze Age and quite modern times. That amounts to saying that there was stagnation for about 3,000 years in this fundamental branch of knowledge, – a period covering half the life-time of the civilization of the Near East, the whole of Græco-Roman civilization, and ending only as modern Europe rose out of the Middle Ages. Here surely is a problem for the historian of science. We shall return to it.

'In the study of the development of man,' writes Partington, 'no part is more significant, even if more neglected, than that concerning the use of materials.' We have spoken of some of the materials used by man in the Old Stone Age. In Egypt the various phases of man's progress are registered by his growing use of things. In the Predynastic period – that is, 4000 and earlier – the Egyptians were using stone, bone, ivory, flint, rock-crystal, quartz, carnelian, agate, hæmatite, amber, and a long list of other semi-precious stones. Then their knowledge of metals begins, and gold, silver, electrum, copper, bronze, iron in small quantities, lead, tin, antimony, platinum, galena, and malachite are added to the list. A

*Add now his later book *What Happened in History* (Pelican).

tomb-painting of the Old Kingdom (2980–2475) shows a metal-worker's shop. Some of the men are engaged in blowing the fire in a furnace through what are probably reeds tipped with clay. Others are cutting and hammering metals. Others again are weighing out precious metals and malachite. Weights at this early period were made of hard stone, cut in geometrical figures. Balances were of the beam type.

We shall not attempt to describe the multifarious techniques of the Egyptians. The newly published *Legacy of Egypt* (Oxford, 1942) has excellent chapters on the subject. Enough has been said to raise the questions which are fundamental for our enquiry, and to these we shall address ourselves. What kind of knowledge is implied in these technical operations? In what sort of way did it fall short of the science of the Greeks? Men were weighing for thousands of years before Archimedes worked out the laws of equilibrium; they must have had practical and intuitional knowledge of the principles involved. What Archimedes did was to sort out the theoretical implications of this practical knowledge and present the resulting body of knowledge as a logically coherent system. Book I of his *Treatise on Plane Equilibriums* starts with seven postulates. *Equal weights at equal distances balance. If unequal weights operate at equal distances, the larger weighs down the smaller.* Such are two of the postulates. They make formal and explicit the kind of assumptions which had been tacitly made for centuries. Their number is reduced to the minimum on which the science can be based. Then, arguing from these postulates, Archimedes works up through a series of propositions to the fundamental theorem, proved first for commensurable and then by *reductio ad absurdum* for incommensurable magnitudes, that *Two magnitudes, whether commensurable or incommensurable, balance at distances reciprocally proportional to the magnitudes.* (*Greek Mathematics*,

Heath, vol. II, p. 75). This is a typical example of what is meant by saying that the empirical knowledge of the East was transformed into theoretical science by the Greeks.

But not all technical practices yield a body of knowledge which can be sorted out so readily into a series of propositions linked together by mathematical logic. Chemical practice, as we have seen, was very far advanced before 1500 B.C. Chemical theory lagged far behind. 'Many of the more historically important ideas were not at first put into words,' writes Haldane. 'They were technical inventions, which were at first handed down by imitation, and only slowly developed a verbal theory. When they did the theory was generally nonsense, but the practice sound. This was obviously the case, for example, until quite recently, with the extraction of metals from their ores.' From the practice of weighing, the Greeks, in the person of Archimedes, succeeded in extracting a science of statics. *They had no more success than the Egyptians in extracting from the crafts of the potter and the smith a sound body of chemical theory.* The successful constitution of a science of statics and the failure to constitute a science of chemistry give us a clue to the strength and the weakness of the Greek scientific achievement.

But the absence of a correct theory must not blind us to the genuinely scientific elements contained in the techniques in which the Egyptian craftsmen excelled, and which the Greeks borrowed from them. Consider, for instance, the science implied in the manufacture of bronze. Bronze is an alloy of copper and tin, which has certain advantages over pure copper. It has a lower melting point. It is harder. It has a finer colour and keeps it better. The Egyptian smiths were aware of these advantages, and experimented until they got the best results. They knew, for instance, that the hardest bronze contains about 12% of tin, that a lower percentage

will not give the required hardness and that a higher percentage makes the bronze more fragile. Many other processes, such as the making of pottery and the making of glass, equally illustrate their skill in applied chemistry. The Greeks borrowed this applied chemistry. But neither Egyptians nor Greeks produced a body of written chemical theory. Why?

Most techniques require at some stage the use of fire. Fire is a great teacher, man's greatest master in the art of chemistry. Pliny has a finely imaginative description of the rôle it has played in civilization (*Natural History*, xxxvi, 68). 'I have now completed,' he writes, 'my description of the works of human ingenuity by which art imitates nature, and with great wonder I observe that fire is almost everywhere the active agent. Fire takes in sand and gives back, now glass, now silver, now minium, now various kinds of lead, now pigments, now medicines. By fire stones are melted into bronze, by fire iron is made and mastered, by fire gold is produced, by fire that stone is calcined which, in the form of cement, holds our houses over our heads. There are some things which it profits to submit more than once to the action of fire. The same original material becomes one thing at a first firing, another at a second, still another at a third. Coal itself, for example, begins to possess its strength only when extinguished, and when it might be thought to be exhausted its virtue is increased. O fire, thou measureless and implacable portion of nature, shall we rightly call thee destroyer or creator?'

But fire is not only a great teacher, it is also a hard taskmaster. It calls for blood, toil, tears, and sweat. 'I have seen the blacksmith at his work at the mouth of his furnace,' writes the Egyptian satirist, 'his fingers like the skin of a crocodile; he smells worse than the roe of a fish.' 'I have not,' he adds, 'seen a blacksmith on a commission, a founder who goes on an embassy.' Fire, therefore, it appears, has effect not only on

things, but on individual men and on the constitution of society. It is the social effect of techniques involving the use of fire, and also of other toilsome techniques, as Gordon Childe has explained, which has determined the development of written science.

The technical revolution of the neolithic age provided the material basis for the civilization of the Near East. That revolution also determined the social character of the civilization that was about to arise. It gradually operated to produce a division in society which had not existed before to any comparable extent. At one pole of society it ranged the workers, at the other the administrators – here the peasant, the potter, and the smith; there the king, the priests, the nobles. Applied chemistry – the practice of transforming things by the agency of fire – was at one pole; applied politics, or the practice of controlling men by fear, at the other. In ancient Egypt the workshops were owned by the king, by corporations of priests, or by a small class of wealthy merchants. Industry was run in close connection with the great estates; the labourers, agricultural or industrial, were serfs or slaves. Such were the main classes in Egyptian society.

Now writing developed step by step with the development of this class-divided civilization, and writing in its origin was an instrument of administration. The scribe belonged, in his humble fashion, to the administrative class. His profession was, in fact, the main avenue by which individuals might climb out of the class of manual workers into the civil service. The literary tradition, accordingly, embraced only such sciences and pseudosciences as were useful for administration or served the needs of the administrative class. Before the end of the fourth millennium, books appear. Thereafter mathematics, surgery, medicine, astrology, alchemy, haruspicy, were made the subject of written treatises. But the practical

applied sciences, the productive techniques, continued to be handed down exclusively by oral tradition among the members of the depressed class in society. The theory continued to be wholly merged in the operations, and could not, without more leisure for reflection, be disengaged from it. The practitioners of the techniques were not only without share in the art of writing which has played a great rôle in enabling the human mind to advance from the multitude of particulars to abstract generalizations; but the establishment of the division in society between the administrative and the working class had lowered their status and their opportunity.

This is the explanation of the paradox noted long ago by Lord Bacon (*N. O.*, I, lxxxv) that the great technical discoveries 'were more ancient than philosophy and the intellectual arts; so that, to speak truth, when contemplation and doctrinal science began, the discovery of useful works ceased'.

These considerations will be found applicable to the whole development of science in antiquity. They are still even to some degree operative to-day. The history of Greek science, which is our main concern, is unintelligible unless they are constantly borne in mind. To borrow the mechanical arts from Egypt or elsewhere was to borrow also the social consequences, at least to some extent. 'What are called the mechanical arts,' says Xenophon, 'carry a social stigma and are rightly dishonoured in our cities. For these arts damage the bodies of those who work at them or who act as overseers, by compelling them to a sedentary life and to an indoor life, and, in some cases, to spend the whole day by the fire. This physical degeneration results also in deterioration of the soul. Furthermore, the workers at these trades simply have not got the time to perform the offices of friendship or citizenship. Consequently they are looked upon as bad friends and bad

patriots, and in some cities, especially the warlike ones, it is not legal for a citizen to ply a mechanical trade.' (*Œconomicus*, iv, 203.)

This contempt of the mechanical arts hindered in Greece, as it did in Egypt, the development of the chemical sciences. Greek science represents an enormous advance on Egyptian science, but it shows the same great limitation. Mathematics, surgery, medicine, and astronomy are not only the main divisions of Egyptian science, but of Greek. Physics, chemistry, mechanics were dishonoured and therefore weak. But the mathematical papyri, which tell us something of the arithmetic, geometry, and mensuration of the Egyptians, and a remarkable fragment of a surgical treatise, the Edwin Smith papyrus, warn us not altogether to despise the written science of the older civilizations of the East.*

The science of Babylonia has the same general characteristics as that of Egypt. From the middle of the fourth millennium the two countries were in constant contact by land and sea. The caravans and the coastal vessels kept up an interchange of ideas as well as of goods. We shall confine ourselves, therefore, to the mention of a few special features. The mathematics and astronomy of Babylonia are generally agreed to have been in advance of those of Egypt. In particular, Babylonian arithmetic, with its positional notation, a device unknown even to the Greeks, has excited the admiration of contemporary students who are busy recovering the knowledge of Babylonian science from the difficult cuneiform scripts. Babylonian arithmetic is beyond anything the Egyptian records reveal. On the other hand, Babylonian medicine, although it shows a steady increase of the observational element in the midst of its magic, its prayers, and its

*For a brief account of the scientific achievement of Egypt and Babylon, see my *Science in Antiquity* (Home Univ. Library).

incantations, has no single document so truly scientific as the Edwin Smith papyrus. Owing, however, to the fragmentary state in which the record of these ancient civilizations has survived, all conclusions based on the evidence at present available are subject to correction. Surgery provides an illustration of this point. We have no Babylonian surgical tablets comparable to the Edwin Smith papyrus; but the code of laws of the Babylonian monarch Hammurabi (2000 B.C.), with its many references to the practitioners of the surgical art, implies a degree of proficiency in that art not suggested by the written record. In most points connected with Babylonian science readers may be referred to Dr George Contenau's *La Médecine en Assyrie et en Babylonie* (Paris, 1938), which is more inclusive than its title suggests and contains a rich bibliography. Serious students of the mathematics of the Old Empires will need O. Neugebauer's *Vorlesungen über die Geschichte der Antiken Mathematischen Wissenschaft* (*erster Band*, *Vorgriechische Mathematik*, Berlin 1934).

Before we leave the question of the pre-Greek cultures of the Ancient East, one point, often overlooked and now given timely stress by Contenau, is worth mention. Egypt had definitely lost its position as a great world power by the beginning of the first millennium B.C., and had come to the end of its creative period in science. But Babylonia, under the Assyrians, the Persians, and the Macedonian Greeks, experienced various revivals both of its political power and creative genius during the last millennium of the pagan era. Its culture, still maintaining its ethnical character, continued its active growth for 1000 years after the Egyptian eclipse, and thus became the contemporary and rival of the culture of the Greeks. The Greek towns which lay along the coastal fringe of Asia Minor were thus in contact with the more active of

the two ancient cultures of the East. History has still something to discover about the mutual influence of the two.

Here we must leave our discussion of science before the Greeks. We cannot offer any description of the culture of the Indus valley, which was contemporary with that of Egypt and Babylon and certainly in contact with both. It is still less known to us than either, since it has been only recently discovered and its written records are as yet undeciphered. Nor shall we speak of the derivative cultures which mediated between the ancient East and Greece – of the graceful Minoan civilization of Crete, whose script is also still undeciphered; of the Hittites, though to them is due the epoch-making discovery of iron; of the Ægean peoples, on whose ruiued civilization the Greek barbarians built; of the Phœnicians, without whose creation of the phonetic alphabet Greek literary culture could not have arisen; or of the Hebrews, whose literature is the most serious ancient rival to that of the Greeks.

CHAPTER TWO

The Chief Periods of Greek Science – The Ionian Dawn. The Milesian School and Heraclitus – The Influence of Techniques.

Chronological divisions of historical movements must always have something arbitrary about them, but they assist the memory at the start. They provide a sort of scaffolding within which the building must be erected. Let us say, then, that the history of Greek science occupies about 900 years and falls into three great divisions of about 300 years each. The first period, which is the special subject of our book, runs from about 600 B.C. to the death of Aristotle in 322 B.C. The second from the foundation of Alexandria to the completion of the Roman conquest of the East about the beginning of the Christian Era. The third covers the first three centuries of the Roman Empire.

Of these 900 years, the first 300 are the most important and the last 300 the least. Inside these divisions the most vital years are: (1) the period 600–400 B.C., when a scientific outlook on the world and society was constituted for the first time in history, and (2) the period 320–120 B.C., when, under the patronage of the Ptolemies, whole branches of science were constituted on what, roughly speaking, might be called their present basis. The first of these periods has been called by Heidel the Heroic Age. The latter might be called the Age of the Text-book. Science, as a separate and orderly branch of knowledge, was constituted in that age. In this book we shall be concerned with the achievement of the Heroic Age, hoping to return to the Age of the Text-book at another time.

The original thing in Greek science at its beginning is that it offers us, for the first time in history, an attempt to supply a purely naturalist interpretation of the universe as a whole. Cosmology takes the place of myth. The ancient empires of the Near East had created or preserved a mass of highly developed agricultural and industrial techniques. They had brought to a certain level of systematization and theoretical development a few officially approved sciences, such as astronomy, mathematics, and medicine. But there is no evidence of an attempt to give a naturalistic explanation of the universe as a whole. There is an official mythology, transmitted in priestly corporations and enshrined in elaborate ceremonial, telling how things came to be as they are. There are no individual thinkers offering a rational substitute for this doctrine over their own names.

This state of science corresponds in general to the stage of social development of the old empires. In the ancient civilizations of the river-valleys life depended on an artificial water-supply. Central governments came into existence, controlling large areas with absolute authority, through their power to give or withhold water. Gigantic works in brick or stone witness to the power of government to direct the co-operative efforts of vast populations. Ziggurats, pyramids, temples, palaces, colossal statues – the dwellings, tombs, and images of kings and gods – apprise us of the organizing ability of the great, the technical skill of the humble, and the superstitions on which society was based. Astronomy was needed to regulate the calendar, geometry to measure the fields, arithmetic and a system of weights and measures to gather the taxes. Medicine had its obvious uses. So, it must be observed, had superstition, and the superstition was such as to preclude the beginning of a scientific cosmology. A sophisticated Greek of the fourth century B.C. cast a glance at the

official religion of Egypt and detected its social utility. The Egyptian law-giver, he remarks, had established so many contemptible superstitions, first, 'because he thought it proper to accustom the masses to obeying any command that was given to them by their superiors', and, second, 'because he judged that he could rely on those who displayed their piety to be equally law-abiding in every other particular'. (Isocrates, *Busiris*.) This is not the type of society in which men with a rational outlook on the world and human life are encouraged to come to the fore.

In Ionia, on the Ægean fringe of the Anatolian mainland, conditions in the sixth century were very different. Political power was in the hands of a mercantile aristocracy and this mercantile aristocracy was actively engaged in promoting the rapid development of techniques on which their prosperity depended. The institution of slavery had not yet developed to a point at which the ruling class regarded techniques with contempt. Wisdom was still practical and fruitful. Miletus, where Natural Philosophy was born, was the most go-ahead town in the Greek world. It was the mother city of a numerous brood of colonies in the Black Sea; and its commerce, whereby its own products were exchanged for those of other lands, ranged far and wide over the Mediterranean. It was in contact with the still-thriving civilization of Mesopotamia by land routes and with Egypt by sea. The information we possess makes it clear that the first philosophers were the active type of man, interested in affairs, one would expect to find in such a town. Everything that we know about them confirms the impression that the range of ideas and the modes of thought they applied to speculation on the nature of things in general were those which they derived from their active interest in practical affairs. They were not recluses engaged in pondering upon abstract questions, they were not

observers of nature' – whatever they may be – but active practical men the novelty of whose philosophy consisted in the fact that, when they turned their minds to wondering how things worked, they did so in the light of everyday experience without regard to ancient myths. Their freedom from dependence on mythological explanations was due to the fact that the comparatively simple political structure of their rising towns did not impose upon them the necessity of governing by superstition, as in the older empires.

Thales, the first of the Milesian philosophers, visited Egypt in the course of business, and brought back from there a knowledge of geometry. He made a new application of the technique which the Egyptians had devised for measuring land. By means of the doctrine of similar triangles, he devised a method of determining the distance of ships at sea. From the Phœnicians he is said to have borrowed improvements in the art of navigating by the stars. By the aid of Babylonian astronomical tables he foretold an eclipse of the sun in 585 B.C. He is said to have made an advance on Egyptian geometry also in the very important sense that he understood better than they the conditions of a general proof. He not only knew that a circle is bisected by its diameter, but proved it. His joint reputation as philosopher and business man is reflected in the story that, being twitted with a lack of practical sense, he confounded his critics by making a fortune in olive oil.

The great renown of Thales, however, rests not on his geometry or his turn for affairs, but on a new commonsense way of looking at the world of things. The Egyptians and the Babylonians had old cosmogonies, part of their religious inheritance, which told how the world had come to be. Since in both countries, in cold fact, the land on which they lived had been won in a desperate struggle with nature by draining

the swamps beside their rivers, naturally enough their cosmogonies embodied the idea that there was too much water about, and that the beginning of things, in any sense that mattered to men, was when some divine being did the equivalent of saying, *Let the dry land appear*. The name of the Babylonian creator was Marduk. In one of the Babylonian legends it says: 'All the lands were sea. ... Marduk bound a rush mat upon the face of the waters, he made dirt and piled it beside the rush mat'. What Thales did was to leave Marduk out. He, too, said that everything was once water. But he thought that earth and everything else had been formed out of water by a natural process, like the silting up of the delta of the Nile. The later Greeks invented a learned compound to describe the novelty of this outlook. They called the Old Ionians *hylozoists*, or Those-who-think-matter-is-alive. That means that they did not think that life, or soul, came into the world from outside, but that what is called life, or soul, or the cause of motion in things, was inherent in matter, was just the way it behaved. The general picture Thales had of things was that the earth is a flat disc floating on water, that there is water above our heads as well as all round us (where else could the rain come from?), that the sun and moon and stars are vapour in a state of incandescence, and that they sail over our heads on the watery firmament above and then sail round, on the sea on which the earth itself is afloat, to their appointed stations for rising in the East. It is an admirable beginning, the whole point of which is that it gathers together into a coherent picture a number of observed facts *without letting Marduk in*.

This naturalistic kind of speculation, once started, made rapid progress. Anaximander, the second name in European philosophy, and also a native of Miletus, had a much more elaborate account of the universe to give, involving more

extensive observation and more profound reflection. As in the case of Thales, the observation and the reflection were turned primarily on techniques, and the phenomena of nature were interpreted in the light of the ideas derived from them. His general idea of how things came to be as they are is this. Once upon a time the four elements of which the world is made lay in a more stratified form: earth, which is the heaviest, at the centre, water covering it, mist above the water, fire embracing all. The fire, heating the water, caused it to evaporate, making the dry land appear, but increasing the volume of mist. The pressure grew to breaking point. The fiery integument of the universe burst and took the form of wheels of fire enclosed in tubes of mist circling round earth and sea. That is the working model of the universe. The heavenly bodies we see circling above our heads are holes in the tubes through which the enclosed fire glows. An eclipse is a closing, or partial closing, of a hole. This very arresting cosmology, while it has obvious reminiscences of the potter's yard, the smithy, or the kitchen, leaves no room for Marduk at all. Even men are accounted for without his help. Anaximander thought that fish, as a form of life, preceded land animals, and that man, accordingly, had once been a fish. But as the dry land appeared, some fish adapted themselves to life on land.

Certain striking advances in logic were also made by this great thinker. He objected to the notion of Thales that everything is water. Why not Earth, or Mist, or Fire, since all change into one another? Better to say that all four are forms of a common *indeterminate substance*. He saw also the naïvety of supporting the earth on water. On what does the water rest? Rather should we say that the world is poised in space yet stays where it is 'because of the equal distance from everything'.

The third thinker, Anaximenes, the last of the Milesians, plumped for Mist as the fundamental form of things. This looks like a step back. But he had, in fact, a most valuable contribution to make. His idea was that everything is Mist, but that it gets harder and heavier according as more of it is packed into a given space. The idea, to judge by his terminology, was suggested to him by the industrial process of felting woven materials by pressure, and was confirmed by his observation of the processes of evaporation and condensation of liquids. *Rarefaction* and *condensation* were his key words. Rarefied Mist is Fire. Condensed Mist becomes first Water and then Earth. He thought also that rarefaction was accompanied by heat and condensation by cold. He 'proved' this by an experiment. You were not just to take his word for it. Open your mouth wide and blow on your hand. The 'rarefied' vapour comes out warm. Now purse your lips together and emit a thin stream of 'condensed' vapour and feel how cold it is. He did not know the true explanation of this phenomenon. Do you?

Observe, in following this succession of thinkers, how their logic, their stock of ideas, their powers of abstraction, increase as they grapple with their problem. It was a great advance in human thinking when Thales reduced the manifold appearances of things to one First Principle. Another great step was taken when Anaximander chose, as his First Principle, not a visible form of things like water, but a concept like the Indeterminate. But Anaximenes was still not content. When Anaximander sought to explain how the different things emerged from the Indeterminate, he gave a reply that was a mere metaphor. He said it was a process of 'separating out'. Anaximenes felt that something more was needed, and came forward with the complementary ideas of Rarefaction and Condensation, which offered an explanation of how quantita-

tive changes could produce qualitative ones. This again marked an advance. It gave a possible explanation of the way in which one fundamental substance might exist in four different states. But something was still lacking – namely, some explanation as to why things should not stay as they are instead of being subject to perpetual change. The Milesians attempted no answer to this question. It occupied the attention of a solitary thinker of another Ionian town, Heraclitus of Ephesus.

As Anaximenes had chosen Mist as his First Principle, Heraclitus chose Fire. He was the philosopher of change. His doctrine has been summed up in the phrase *Everything flows;* but his choice of Fire as his First Principle was probably not due, as is often said, to its being the most impermanent of things, but to its being the active agent which produces change in so many technical and natural processes. Still more important was his idea of Tension, brought in to explain the relative permanence and fundamental impermanence of things. It is one of the richest and most helpful ideas of the old philosophers, not a whit reduced in significance when we remember that it, too, had its origin in the techniques of the time. The doctrine of *Opposite Tension* which Heraclitus applied to the interpretation of nature was derived, as his own words inform us, from his observation of the state of the string in the bow and the lyre. According to Heraclitus there is in things a force that moves them on the Upward Path to Fire, and an opposite force that moves them on the Downward Path to Earth. The existence of matter in any particular state is the result of a balance of opposing forces, of Tension. Even the most stable things in appearance are the battleground of opposing forces, and their stability is only relative. Once force is gradually gaining on the other all the time. Nature as a whole is either on the Upward Path to Fire or

on the Downward Path to Earth. Its mode of existence is an eternal oscillation between these two extremes.

There is great danger, in discussing these old thinkers, that one may read into them the meaning of a later age. It must always be remembered that they were ignorant of all the accumulated knowledge of modern science and all the refinement of ideas that centuries of philosophical discussion have produced. In the world of thought, as in the world of nature, everything flows. The very words with which we translate the sayings of Heraclitus are charged with meanings unknown to him. It takes an effort of historical research and of historical imagination to put oneself back into the frame of mind of this great old thinker when he supposed himself to have solved the riddle of the universe by saying that there was a tension in things, 'like the bow and the lyre'. But, if there is danger of exaggerating the import of these ancient philosophies, there is also danger of denuding them of significance. The judgment of Brunet and Mieli (*Histoire des Sciences. Antiquité*, p. 114), whose book is one of the latest and one of the best on the subject, is worth quoting. 'These philosophers are,' they write, 'according to the accurate title given to them in antiquity, *physiologoi*, that is to say, observers of nature. ... They observe the phenomena which present themselves to their eyes, and, putting aside all supernatural or mystical intervention, they endeavour to give strictly natural explanations of them. It is in this sense, and by their rejection of all magical intervention, that they make the decisive step towards science and mark the beginning, at least the conscious and systematic beginning, of a positive method applied to the interpretation of the facts of nature.' This judgment is worth quoting, but it needs supplementing. The Milesians were not simply observers of nature. They were observers of nature whose eyes had been quickened, whose attention

directed, and whose selection of phenomena to be observed had been conditioned, by familiarity with a certain range of techniques. The novelty of their modes of thought is only negatively explained by their rejection of mystical or supernatural intervention. It is its positive content that is decisive. Its positive content is drawn from the techniques of the age.

CHAPTER THREE

Pythagoras – The Religious Tradition in Greek Philosophy The Mathematical Universe

LATER Greeks recognized in the history of their thought about the nature of things a double tradition – the purely naturalistic, or materialistic, or, as they sometimes called it, atheistic tradition of Ionia, and the religious tradition which originated with Pythagoras in Magna Graecia in the West.

Plato, in the tenth book of his *Laws*, gives a brief characterization of both systems of thought. The opinions he ascribes to the Ionian naturalists are as follows: The four elements, Earth, Air, Fire, and Water, all exist by nature and chance, none of them by design or providence. The bodies which come next in order – the earth, the sun, the moon, the stars – have been created by these absolutely inanimate elements, which are moved by some inherent force according to certain affinities among them. In this way the whole heaven has been created and all that is in the heaven, as well as all plants and animals. The seasons also result from the action of these elements, not from the action of mind, or God, or providence, but by nature and chance only. Design sprang up afterwards and out of these. It is mortal and of mortal birth. The various arts, embodiments of design, have sprung up to co-operate with nature, – arts such as medicine, husbandry, and even legislation. The gods likewise are products, not of nature, but of design, being constituted by the laws of the different states in which they are worshipped. Morality also, like religion, is a product of human design. The principles of justice have no

existence in nature; they are a mere convention. To sum up, the natural philosophers say that Fire, Water, Earth, and Air are the first elements of all things, that these constitute Nature, and that the soul is formed out of these afterwards.

Plato next sets forth the main ideas of the religious tradition of thought, which is also his own. According to this view, the soul is the first of things. She is before all bodies, and is the chief author of their changes and transpositions. The things of the soul come before the things of the body. That is to say, Thought, Attention, Mind, Design, Law are prior to the qualities of matter. Design, or Mind, or Providence comes first, and after it come nature and the works of nature. What is called nature is under the government of Design and Mind. This is the tradition which is said to have originated with Pythagoras. Henceforth we shall need to keep in mind the double tradition. Both traditions are often embodied in a single philosopher.

Pythagoras, for example, is not only the founder of the religious tradition; he is also one of the greatest of Greek scientists. An Ionian Greek by origin, who probably (as is also said of Thales) had Phœnician blood in his veins, he emigrated to the West when the advance of the Persian power to the Ægean threatened the liberties of the Asiatic Greeks, and settled in Croton in southern Italy. He is the founder of European culture in the Western Mediterranean sphere.

Pythagoras was a native of the island of Samos, which at this time, like the city of Miletus, which saw the birth of Greek science, was a commercial power in a vigorous, even violent, stage of growth. Its dictator, Polycrates, had broken the power of the landed aristocracy and was running the island with the backing of the merchant class. In their interest he enlarged and improved the harbour, and, as his capital city grew, he caused to be executed one of the most astonish-

ing feats of ancient engineering. Fetching an engineer from Megara, one Eupalinus by name, he had him run a tunnel through the hill of Kastro to serve as an aqueduct to supply the town. The tunnel, which is over 900 yards in length, was begun from both ends. Modern excavations show that when the two digging parties met in the centre their borings fell short of exact coincidence only by a couple of feet.

The fact is full of warning and instruction for the historian of science. If we were dependent on the literary record alone, we should have to wait for a late writer, Hero of Alexandria, who probably lived in the second century A.D., for a geometrical construction explaining how to perform this feat. But the job was done, and well done, 600 years earlier, and we may be certain that the necessary mathematical knowledge also existed then, though we have no record of it.

Pythagoras was about forty years of age when, about the year 530 B.C., the Persian conquest of Ionia disturbed his prospects in Samos and he fled for refuge to Croton. Here, as no doubt he knew before he made the venture, he found a commercial city not unlike his own. He was an active politician, and the probability is that he attached himself to the merchant class in his new home, which, here as elsewhere, occupied a middle position between the land-owning aristocracy and the peasants and workers. He became enormously influential in his new home. Its political and religious life were reshaped by him. Professor George Thomson, in his *Æschylus and Athens*, compares his position to that of Calvin at Geneva.

Pythagoras, however, as we have said, was not only a religious reformer and politician, but a scientist. We shall understand his science better if we do not forget his religion and his politics, for they were intimately blended. The Pythagorean community was a religious brotherhood for the

practice of asceticism and the study of mathematics. The brethren were required every day to conduct, in private meditation, an examination of conscience. They believed in the immortality of the soul and its transmigration; the perishable body was but a tomb or prison which the soul inhabited for a time. These beliefs they held in common with other adherents of the mystery religions then widespread in Greece. Pythagoreanism was, in effect, a sophisticated form of mystery religion. The peculiarity of the system was that it found in mathematics a key to the riddle of the universe and an instrument for the purification of the soul. 'The function of geometry,' says Plutarch, speaking like a good Pythagorean, 'is to draw us away from the sensible and the perishable to the intelligible and the eternal. *For the contemplation of the eternal is the end of philosophy, as the contemplation of the mysteries is the end of religion.*' The parallel is significant. The Pythagoreans were the originators of the religious attitude towards mathematics. They did not indeed, at least in the earlier generations of the school, despise the practical applications of mathematics. Systematic town-planning, which began in Greece at this period, is due to Pythagorean influence. But the growth of religious mysticism based on mathematics must be ascribed to this school.

The school quickly registered remarkable advances in geometry and the theory of numbers. It is generally agreed that by the middle of the fifth century they had arrived at most of the results which are systematized by Euclid in Books I, II, VII, and IX of his *Elements*. This is a scientific achievement of the first order. But if you study their mathematics in the sober pages of Euclid's famous textbook, you will not recover its other aspect, the religious fervour with which their views were held. A quotation from a fifth century Pythagorean will help us to do that.

'Consider,' exclaims Philolaus, 'the effects and the nature of number according to the power that resides in the decad. It is great, all-powerful, all-sufficing, the first principle and the guide in life of Gods, of Heaven, of Men. Without it all is without limit, obscure, indiscernible. The nature of number is to be a standard of reference, of guidance, and of instruction in every doubt and difficulty. Were it not for number and its nature, nothing that exists would be clear to anybody either in itself or in its relation to other things. ... You can observe the power of number exercising itself not only in the affairs of demons and of gods, but in all the acts and the thoughts of men, in all handicrafts and in music. Nor does harmony and the nature of number admit of any falsity. Falsity is in no way akin to it. Only to the unlimited, the unintelligible, the irrational, do falseness and envy belong.'

This passage, however, does something more than emphasize the religious aspect of Pythagorean mathematics. It also stresses the importance of mathematics for the practical arts. This is characteristic of the early period of Greek philosophy, and remains to some extent characteristic of it to the end. Plato, as may be seen from the quotation with which we began this chapter, associated the Ionian philosophy with a definite theory as to the nature and social function of the practical arts. For the early Ionians there was no essential difference between natural and technical processes. The claim of the early Ionians that nature was intelligible was based on their view that the practical arts were intelligent efforts of men to co-operate with nature for their own good. The Pythagoreans, the prime movers in the next great philosophical movement, still have the same outlook. Number, for them, is not only the first principle of the heavens, but exhibits its power also 'in all the handicrafts'. The harmony produced by number will still be our theme,

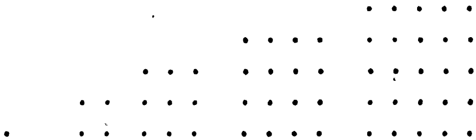
no matter what part of the Pythagorean universe we examine. Here we shall confine our attention to the two branches of knowledge most powerfully influenced by Pythagorean mathematical theory, – cosmology and music.

The cosmology of the Pythagoreans is very curious and very important. They did not, like the Ionians, try to describe the universe in terms of the behaviour of certain material elements and physical processes. They described it exclusively in terms of number. Aristotle said long afterwards that they took number to be the matter as well as the form of the universe. Numbers constituted the actual stuff of which their world was made. They called a point One, a line Two, a surface Three, a solid Four, according to the minimum number of points necessary to define each of these dimensions. But their points had bulk, their lines breadth, their surfaces depth. Points added up to lines, lines to surfaces, surfaces to solids. Out of their One, Two, Three, and Four they could really build a world. No wonder that Ten, the sum of these numbers, was a sacred and omnipotent power. It follows also that the theory of numbers which they brought to such perfection was for them something more than mathematics. It was physics.

The identification of numbers with things is apt to appear puzzling to the student. It will be found less puzzling if we follow the clue provided by the mathematical procedure which led the Pythagoreans to this view. We have spoken of their study of the theory of numbers. In this study their method was to employ what are called figurate numbers. They represented the triangular numbers thus:

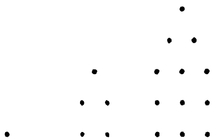
. and so on.

The square numbers thus:



and so on.

And the pentagonal numbers thus:



and so on.

It was this new technique of analysing the properties of numbers which made possible their identification of numbers with things and determined, as we shall see, the peculiarity of their cosmological system.

This mathematical philosophy appeared as a rival to the natural philosophy of the Ionians. And here it becomes immediately apparent that, as a theory of the universe, it contained less of sensuous intuition and more of abstract thought than the Ionian view. Mathematical relations now take the place of physical processes or states, like rarefaction and condensation, and tension. The universe, so it appeared to the Pythagoreans, could be better, and more quickly, understood by drawing diagrams on sand than by thinking about phenomena like raised beaches, silting up of river mouths, evaporation, felting, and so forth. Herein lay a danger. This mathematical approach was adjusted both to the religious and social preconceptions of the school. Mathematics not only seemed to provide a better explanation of things than the Ionian view. It kept the souls of the brethren pure from contact with the earthly, the material, and suited the changing temper of a world in which contempt for manual

labour kept pace with the growth of slavery. In a society in which contact with the technical processes of production became ever more shameful, as being fit only for slaves, it was found extraordinarily fortunate that the secret constitution of things should be revealed, not to those who manipulated them, not to those who worked with fire, but to those who drew patterns on the sand. For Heraclitus, who came at the end of a school of thought in which industrial technique had played a prominent rôle in providing the stock of ideas by which nature was explained, nothing seemed more natural than to regard fire, the chief agent in the technical manipulation of material things, as the fundamental element. The substitution of number for fire as the First Principle marks a stage in the separation of philosophy from the technique of production. This separation is of fundamental importance in the interpretation of the history of Greek thought. Henceforth the banausic associations of the oven, the soldering-iron, the bellows, and the potter's wheel reduce their influence on Greek thought in comparison with the more gentlemanly pursuit of theory of numbers and geometry.

The Pythagoreans, having constructed matter out of numbers, next proceeded to arrange the main members of the universe according to a plan in which there was a little observation of nature and a lot of *a priori* mathematical reasoning. Since they attached moral and æsthetic values to mathematical relations, and since they held the heavenly bodies to be divine, they had little difficulty in deciding that the heavenly bodies are perfect spheres and move in perfect circles, the word 'perfect' here having a moral as well as a mathematical significance. It has not, in fact, proved true that the heavenly bodies are perfect spheres, nor that they move in perfect circles. Nevertheless the fact that the Pytha-

goreans made great advances in mathematics and that they applied their new technique to astronomy made them pioneers in this domain. Their plan of the universe is, historically, of great importance. In the centre they put a mass of fire; round it revolved the earth, the moon, the sun, the five planets, and the heaven of the fixed stars. The distances of the heavenly bodies from the central fire they supposed to correspond to the intervals of the notes in the musical scale. This provided a sort of ground plan for subsequent workers. Gone are the tubes of fire of Anaximander, which seem primitive in one aspect, but which attempted to supply a mechanical model of the universe. Their place is taken by a purely geometrical astronomy which aims at mapping out the positions of heavenly bodies conceived of as divine. Vast improvements in the understanding of the relative sizes, distances, and positions of the heavenly bodies, the result of the application of a new mathematical technique to a few observed facts, were to transform in the course of centuries the simple Pythagorean plan into the complicated system of Ptolemy which was not seriously attacked until the sixteenth century of our own era. But from now on the heavenly bodies, being divine and therefore immortal, cease to have a history. They are removed, though not without a sharp struggle, from the sphere of natural philosophy and incorporated in theology.

The Pythagorean contribution to music, or, to be more accurate, to acoustics, is of even greater interest than their cosmology. How did they make the discovery of the fixed intervals in the musical scale? It seems reasonable to claim it as an early triumph of the method of observation and experiment. A story is told about it in a late writer, Boethius, who belongs to the sixth century A.D. Since it is the kind of story that antiquity was more inclined to forget than to invent, I

agree with Brunet and Mieli that it is likely to be true. Here is the narration of Boethius, slightly condensed.

Pythagoras, haunted by the problem of giving a mathematical explanation of the fixed intervals in the scale, happened, by the grace of God, to pass a blacksmith's shop, and found his attention gripped by the more or less musical chime rung out by the hammers on the anvil. It was an opportunity to investigate this problem under new conditions which he could not resist. In he went and observed long. Then he had an idea that the different notes might be proportioned to the strength of the men. 'Would they change their hammers round?' It was plain that his first idea was wrong, for the chime was unaltered. The explanation must lie in the hammers themselves, not in the men.

There were five hammers in action. 'Might he weigh them?' Ah, miracle or miracles, the weights of four of them were in a proportion of 12, 9, 8, 6. The fifth, the weight of which bore no significant numerical relation to the rest, was the one that was spoiling the perfection of the chime. It was rejected, and Pythagoras listened again. Yes, the heaviest hammer, which was double the weight of the lightest, gave him the octave lower. The doctrine of the arithmetic and harmonic mean provided him with the clue to the fact that the other two hammers gave the other fixed notes in the scale. Surely it was the will of God that he had passed that blacksmith's shop. He hurried home to continue his experiments – this time, one might say, under laboratory conditions.

Did the whole reason for the harmony of those notes consist in the mathematical relations which had been observed? Pythagoras tried it out in a new medium, vibrating strings. He found that the note given was proportioned to the length. But what about the thickness and the tension of the strings? Into these two questions also he probed. Finally, returning

to the relations of length he tried the matter out again on reed pipes of appropriate dimensions. Then at last he was sure. Such is the tradition Boethius records.

There is some confusion in the tradition. The experiment on the hammers could not give the results it is said to have given. If he did experiment on tension, his findings must have puzzled him. The number of vibrations in a stretched cord depends not on the weight which stretches it, but on the square root of the weight. We lack evidence that Pythagoras, or any ancient, knew this. Nevertheless these experiments are of crucial significance in the history of science. It is admitted that the Greeks never brought experiment to anything like the system and thoroughness which have characterized it in modern times. But that is not to admit that they never practised it. Brunet and Mieli are right to conclude from these experiments that 'they constitute a formal disproof of the belief affected by many that the Greeks did not know experimental science. It is further to be remarked', they add, 'that it is to Pythagoras himself that tradition ascribes this discovery, and in this case one may, with all probability, admit the attribution. The development of experimental method in acoustics and in other parts of physics is one of the fairest titles to glory of the Pythagorean school.' (*Op. cit.*, p. 121.)

It remains to add one word about the crisis that overtook the Pythagorean geometrical view of the world about the middle of the fifth century. The Pythagoreans, as I have explained, built up their world out of points with magnitude. It might not be possible to tell how many points there were in any particular line; but, theoretically, they were finite in number. Then, with the progress of their own mathematical science, the foundation of their universe was suddenly swept away. It was discovered that the diagonal and the side of a

square are incommensurable. $\sqrt{2}$ is an 'irrational' number. The term originated with them and indicates their shock when they, who held that number and reason were the same thing, found that they could not express $\sqrt{2}$ by any number. Their confusion was great. If the diagonal and the side of a square are incommensurable, it follows that lines are infinitely divisible. If lines are infinitely divisible, the little points of which the Pythagoreans built their universe do not exist. Or, if they do exist, they have got to be described in other than purely mathematical terms. In the fifth century B.C. they also had their crisis in physics.

CHAPTER FOUR

Parmenides and the Attack on Observational Science – Empedocles and Anaxagoras to the Rescue – The Atoms of Democritus

THE natural philosophy of the Ionians, simple as it is, comprises two elements. There is an element of observation and an element of thought. In order to explain the phenomena of the senses they had had to invent a system of abstract ideas. Earth and water, it is true, might seem names for things seen and felt, but even these terms pass over into the more general ideas of solid and liquid; that is to say, they tend to become abstract terms. Still more clearly abstract are such ideas as the Indeterminate, or Condensation and Rarefaction, or Tension. The terms may, indeed, be taken from everyday life, but, as used by the philosophers, they become names of concepts invited to explain percepts. The distinction between the mind and the senses begins to appear. The first to express an awareness of this distinction was the deep thinker Heraclitus. 'The eyes and ears,' he said, 'are bad witnesses for men, if the mind cannot interpret what they say.' And again, as if aware of the newness and difficulty of this distinction between thought and sense, he observes: 'Of all those whose discourse I have heard there is not one who attains to the understanding that wisdom is apart from other things'.

Once the distinction had become clear there was bound to arise controversy as to which of the two, reason or sense, was the true method of approach to the understanding of nature. In the attempt to solve this problem the Pythagoreans played a prominent part. A younger contemporary of Pythagoras,

and an adherent of his school, Alcmaeon of Croton, in the endeavour to expose the physical basis of sense-experience, laid the foundations of experimental physiology and empirical psychology. He dissected and vivisected animals. He discovered, among other things, the optic nerve, and he came to the correct conclusion that the brain is the central organ of sensation. His description of the tongue as the organ of taste is worth quoting. 'It is with the tongue that we discern tastes. For this being warm and soft dissolves the sapid particles by its heat, while by the porousness and delicacy of its structure it admits them into its substance and transmits them to the sensorium.' These striking words, which formed part of a general account of the physiology of sensation, are proof both of his powers of observation and of the systematic researches carried on in the Pythagorean school.

The achievements of the Pythagorean experimenters soon came under the criticism of philosophers who believed in seeking truth by pure reason alone unaided by the evidence of the senses. Their criticism, such as it is, has its place in the history of science. The attack on the senses was opened by the founder of another Italian school, Parmenides of Elea, the second of the religious philosophers of the Greeks. He composed a poem in two books, called respectively *The Way of Truth* and *The Way of Opinion*. In the first he propounded a view of the nature of reality based on the exclusive use of reason; in the second it is probable that he set forth, and rejected, the Pythagorean system which contained too much observation for his liking. Considerable fragments of his poem survive. One passage contains his attack on the experimentalists, which is sweeping and direct. 'Turn your mind away from this path of enquiry,' he cries. 'Let not the habit engrained by manifold experience force you along this path, to make an instrument of the blind eye, the echoing ear, and

the tongue, but test by reason my contribution to the great debate.'

What had Parmenides in mind when he attacked the use of the eye, the ear, and the tongue? Most commentators seem to believe that he was addressing a general caution to mankind to beware of the treachery of the senses. But his words preclude this interpretation: he specifically attacks a method of research. Nor is it difficult to suggest the contemporary activities which he denounced. The astronomical activities of the Ionian school were carried on at this time in an observatory on the island of Tenedos. This affords an outstanding example of the use of the 'blind eye' in the interpretation of the universe. The 'echoing ear' irresistibly suggests the acoustic experiments of the Pythagoreans. The tongue, no doubt, is to be understood, not as the organ of speech, as so many commentators strangely suppose, but as the organ of taste so accurately described by Alcmaeon. The Hippocratic doctors, whose contribution to science we shall discuss in our next chapter, were already testing by taste the waters of every locality in which they settled, not to mention the humours and *excreta* of the human body. It was against an established practice of observational science applied in a variety of different fields that Parmenides' attack was directed.

If Parmenides thus fiercely attacked the scientists, of what positive opinion was he the champion? Like his contemporary, Heraclitus of Ephesus, at the other end of the Greek-speaking world, he was preoccupied with the problem of reason and the senses, and he thought that one should follow reason exclusively. His reason, however, led him to a diametrically opposite conclusion from that of Heraclitus. Heraclitus said: Everything changes. Parmenides said: Nothing changes. Heraclitus said: Wisdom is nothing but the understanding of the way in which the world works.

Parmenides said that the universe did not really work at all, but remained absolutely still. For him change, motion, variety, were all illusions of sense.

He had an argument, but no evidence, for this. He started off with two general and contradictory ideas, Being and Not-Being, What-is and What-is-not, which between them exhaust the universe of discourse. He then advanced two simple propositions: What-is is; What-is-not is not. If you take these propositions seriously it is impossible to introduce change, motion, or variety into the universe. Being can suffer change of any kind only by admixture of something else – that is, of Not-Being. But Not-Being does not exist. Therefore there is nothing in existence but absolute fulness of Being. The idea of Anaximenes, that you could change the primary substance from Earth into Water, from Water into Mist, by having less of it in a given space, can only mean that you dilute it, so to speak, with empty space, with nothing, with What-is-not, which does not exist. Satisfied with this reasoning, Parmenides asserted that the reality was a solid uncreated eternal motionless changeless uniform sphere. There is nothing wrong with this argument except that it flouts all experience. It is a way of thinking about things which is perpetually refuted by actual contact with things. Hence the warning against reliance on ear, eye, or tongue. With Parmenides thought finds itself at variance with action, with life.

What is the meaning of this strange philosophy of Parmenides? What is the significance of the fact that man, proud in the possession of a newly defined activity, reason, ventures by its aid to deny the reality of the manifold world of sense? We must understand the position of Parmenides in its double aspect, as a protest and an assertion. On the one hand he is protesting against the atheistic consequences of the Ionian

philosophy which was banishing the divine from nature. On the other hand he is asserting the primacy of a new technique now coming into notice for the first time, the technique of logical argument. Parmenides has seized hold of the logical principle of contradiction. He cannot admit that a thing can both be and not be at the same time; yet this admission is necessary if we are to account for change. For him, a man principally occupied with religious conceptions (historically he should be regarded as a reformer of Pythagorean theology), it meant nothing to throw change overboard. He was, indeed, glad to do so. But, from the point of view of the old Ionian school, whose modes of philosophical explanation had arisen in close association with the active processes of altering nature which are the business of techniques, it was impossible to dispense with change. They could not admit that philosophy should condemn and reject life. The controversy went deeper than words. Eleaticism marks a further stage in the separation of philosophy from its roots in practical life.

The next great thinker among the western Greeks, Empedocles of Agrigentum in Sicily, did not find the stagnant philosophy of Parmenides to his taste. He, too, cast the exposition of his views into the form of verse, and in some extant lines we find his reply to the Parmenidean attack on the senses. He, of course, recognizes the fallibility of the senses, but defends the critical employment of the evidence they supply. 'Go to, now,' he writes, 'consider with all thy senses each thing in the way in which it is clear. Hold nothing that thou seest in greater credence than what thou hearest, nor value thy resounding ear above the clear instruction of thy tongue; and do not withhold thy confidence from any other bodily part by which there is an opening for understanding, but consider everything in the way in which it is clear.'

Empedocles took up the championship of the senses because, like the old Ionians, he drew upon techniques for the ideas by which he sought to explain the processes of nature. The mixing of colours for painting, bread-making, and the sling, he mentions as sources of his ideas. Also he was himself an experimentalist like Pythagoras and Alcmaeon. His great contribution to knowledge was his experimental demonstration of the corporeality of the viewless air. Before him air had not been distinguished from empty space. The four recognized forms of matter had not been Earth, *Air*, Fire, and Water, but Earth, *Mist*, Fire, and Water. Empedocles undertook an experimental investigation of the air we breathe. The Greeks had a water-clock, *clepsydra*,* which consisted essentially of a hollow cylinder, open at one end and terminating at the other in a cone with a small aperture at the tip. The clepsydra was used to measure time by filling it with water and letting the water escape through the small hole at the tip of the cone. Like the sand in an hour-glass, the water ran through in a measured interval of time. Empedocles now showed that, if the open end of the clepsydra was thrust under water while a finger was held over the hole in the tip of the cone, the contained air prevented the water from entering the clepsydra. Conversely, the full clock, though turned upside-down, could not empty itself so long as a finger was kept over the hole. The pressure of the air kept the water in. By these experiments he demonstrated the fact that the invisible air was something that could occupy space and exert power. The experiment is all the more interesting in that it was but part of a more comprehensive effort to establish a relation between the external atmosphere and the movement of the blood. He thought the blood moved up and down in the body. As it rose it drove the air out; as it sank it let it in again.

*See note, p. 62.

Both the method and the conclusion are memorable. The former affords further illustration of the fact that the Greeks, though they had nothing like the modern technique of interrogating nature by an elaborate system of experiments with instruments designed for the purpose, yet were not without the practice of experimental research. As for the result established, the proof of the corporeality of the air, it seems to have been too little noted that it was crucial for the whole future of Greek theory on the nature of matter and the degree of validity of sense-evidence. It had now been experimentally shown that matter could exist in a form too fine to be apprehended by sight, and yet, in that form, exert considerable power. The bearing of this went far beyond the single point established. Empedocles had not merely shown the corporeal nature of air; he had shown how we can overcome the limitations of our sensuous apprehension and discover, by a process of inference based on observation, truths we cannot directly perceive. He had, by his cautious and critical use of the senses, conquered in the name of science a world that lay beyond the normal range of man's perceptions. He had revealed the existence of an imperceptible physical universe by examining its effects on the perceptible world.

The importance of this as a step towards the atomic theory was decisive. For the Atomists, if we may anticipate our account of their system, it was essential to show that 'Nature works by unseen bodies'. Of the truth of this proposition the power that could be exerted by the invisible air was the most convincing proof. In his first book of the *De Rerum Natura* Lucretius gathers together the traditional proofs that nature works by unseen bodies. He makes a list of 'bodies that are in the number of things but which yet cannot be seen'. Of these the most important is air. 'First of all,' he writes, 'the force of the wind when aroused beats on

the harbours and whelms huge ships and scatters clouds; sometimes in swift whirling eddy it scours the plains and strews them with huge trees and scourges the mountain summits with forest-rending blasts; so fiercely does the wind rave with a shrill howling and rage with threatening roar. *Winds therefore sure enough are unseen bodies* ... since in their works and ways they are found to rival great rivers which are of visible body.'

Nothing else in Empedocles was equally important with his defence of the method of observation and his famous experiment. In cosmology he was an eclectic. He adopted as his first principles all the four states of matter recognized by his predecessors, except of course that Air now took the place of Mist. Earth, Air, Fire, and Water he called the Roots of all things. As an equivalent for the Tension of Heraclitus he taught that two forces, Love and Hate, set the elements in motion, Love tending to draw the four elements into a mixture and Hate to separate them again. Under the sway of these forces nature went through a cycle like that imagined by Heraclitus.

With these cosmological ideas he coupled a theory of sense-perception which shows that the true nature of the problem had not been grasped. He thought that, as men are composed of the same elements as the rest of nature, sense-perception might be explained on the basis of a physical intermingling of like elements. By Fire we recognize Fire, by Water Water, and so on. But perception is something different from a physical mixing of material substances. When salt dissolves in water the process is not accompanied by consciousness, at least so far as we know. It is consciousness that needs to be explained. His biological speculations have more interest. He thought that the earth, when she was younger, had produced a much greater variety of living things, but that 'many

races of living things must have been unable to beget and continue their breed. For in the case of every species that now exists, either craft or courage or speed has from the beginning of its existence protected and preserved it.' Here is a clear hint of the doctrine of the survival of the fittest. Noteworthy also is the suggestion that the earth once had powers she does does not now possess.

Empedocles, by choosing four first principles, no doubt hoped to circumvent the logic of Parmenides. By introducing plurality into the first principles, he sought to preserve the possibility of change and motion. In this, he did not squarely meet the logic of the great Monist, but he at least revealed his determination to evade its consequences. A similar determination was shown by Anaxagoras of Clazomenae, a philosopher of the Ionian school brought to Athens by Pericles about the middle of the fifth century. He went as far as it is possible to go in the direction of pluralism. According to him, the first principles, which he called 'seeds', are infinite in number and variety, and every one of them contains a little of all the qualities of which our senses give us knowledge. He was led to this view by his meditations on physiology. How does bread, for instance, when we eat it, turn into bones, flesh, blood, sinews, skin, hair, and the rest, unless the particles of wheat contain, in some hidden form, all the variety of qualities which are later manifested in the several constituents of the body? Digestion must be a sorting out of elements already there.

These considerations of Anaxagoras, deduced from physiological observations, show an increasing awareness of the complexity of the problem of the structure of matter. He approached the same problem also from the physical side. Aristotle (*Physics*, IV, 6, 213a) speaks of him as repeating the experiment of Empedocles with the clepsydra and further

demonstrating the resistant power of air by puffing up bladders and endeavouring to compress them. He also contributed to the debate on the validity of sense-evidence. There can be no question but that he regarded sense-evidence as indispensable for the investigation of nature, but, like Empedocles, he was concerned to show that there were physical processes too subtle for our senses to perceive directly. He devised a choice experimental demonstration of this fact. He took two vessels, one containing a white liquid, the other a black. He transferred one liquid into the other drop by drop. Physically there must be a change of colour with every drop, but the eye is not able to discern it till several drops have been let fall. It is hardly possible to imagine a neater demonstration of the limits of sense perception. We shall have occasion later to speak of the reaction of the Athenian public to the presence of an Ionian philosopher in their midst. Anaxagoras was not one of those who was prepared to yield astronomy to the theologians. In astronomy he followed the old Ionians, and his hardihood brought him into trouble.

It only remains, among fifth-century speculations on the nature of matter and the structure and workings of the universe, to speak of the atomic theory of Democritus. The theory has been revived in modern times, and the degree of similarity between the theory of Democritus and that of Dalton entitles the ancient speculation to be described as a wonderful anticipation of the conclusions of later experimental science. This is true, though it is easy to misunderstand the relation between ancient and modern atomism. 'Atomism was a brilliant hypothesis,' writes Cornford (*Before and After Socrates*, p. 25). 'Revived by modern science, it has led to the most important discoveries in chemistry and physics.' Surely this is to put the cart before the horse. It ought to read: 'Atomism was a brilliant hypothesis; important

discoveries in modern chemistry led to its revival'. In the long series of researches that led to the enunciation by Dalton of his atomic theory in the first decade of the nineteenth century the speculations of Democritus played no part. The true glory of the atomism of Democritus is that it answered better than any other current theory the problems of his own day. It is the culmination in antiquity of the movement of rational speculation on the nature of the universe begun by Thales. Its factual basis consists in observations of technical and natural processes by the unaided senses, together with a few experimental demonstrations of the kind we have described. Its theoretical merit is to have reduced these results to a greater logical coherence than any other ancient system. The need for a renovation of the whole ancient system of speculation did not arise until the advance of techniques had put into man's hands instruments of investigation which enormously extended the range and accuracy of his sense perceptions. Ancient science had clearly established the fact that Nature works by unseen bodies. Modern science has devised progressively better methods of seeing the unseen.

The atomism of the ancients asserted that the universe was made up of two things, the atoms and the void. The void, or empty space, was infinite in extent, the atoms infinite in number. The atoms were all alike in substance, but might differ from one another in size, shape, arrangement, and position. The atoms, like the One of Parmenides, were uncreated and eternal, solid and uniform in substance, in themselves incapable of change; but, being in perpetual motion in the void, they wove, by their various combinations and dissolutions, all the pageant of our changing world. Thus was provided an element of eternal rest to satisfy Parmenides and an element of eternal change to satisfy Heraclitus. A world

of Being underlay the world of Becoming. But the achievement of this reconciliation required a bold revision of the logic of Parmenides in the light of experience. The existence of void had to be admitted equally with the existence of matter. The experience of the fact of change compelled the assertion that What-is-not exists just as certainly as What-is. Matter, or the atom, was defined as an absolute plenum, void as an absolute vacuum. The atom was completely impenetrable, void completely penetrable.

One originality of atomism was the assertion of the existence of the void. Another was the concept of the atom itself. The Pythagoreans, it will be remembered, had attempted to build the universe out of points with bulk, and when they discovered that space was infinitely divisible, they could no longer provide any clear definition of a point with bulk. For the mathematician a point simply marked position but did not occupy space. Out of such points nothing could be built. Democritus defined the unit of which the universe is built not in mathematical but in physical terms. His atoms, having bulk, were spatially divisible, but physically indivisible. The concept of impenetrability, which derives from the Parmenidean One, was the essential quality of the atom. Democritus thus presented the Pythagoreans with a solid little brick with which to build their mathematical world. The atomic theory also solved the problem of Anaxagoras, so far as it is permissible to speak of a solution in ancient times when theories of the constitution of matter could only be more or less logical and could not be put to the proof. On the atomic hypothesis the problem of digestion and assimilation of food was easily solved. There was no difficulty in supposing that a fresh arrangement of the atoms might transform bread into flesh and blood, just as a fresh arrangement of the letters of the alphabet could transform a Tragedy into a Comedy. The

illustration is an ancient one. By such analogies did the old Atomists eke out the inevitable paucity of their observed facts.

Democritus made also a contribution of capital importance to the problem of sense-perception. Every perceptible thing, according to him, is an arrangement of atoms which differ only in size and shape. The *qualities* which we ascribe to this arrangement of atoms – the colours, the tastes, the noises, the smells, the tactile qualities – are not qualities of the bodies in themselves, but effects of the bodies on our organs of sense. Galileo in his day could do no better than to repeat this brilliant suggestion.

To the other merits of his system must be added his superb powers of generalization. His cosmology followed the general Ionian plan, and need not detain us here. But the great principles on which his argument rested were enunciated with a new clarity. 'Nothing is created out of nothing.' 'By necessity were fore-ordained all things that were and are and are to be.' In such terms did he announce for the first time the doctrines of the conservation of matter and the reign of universal law. The disappearance of his book is probably the greatest loss we have suffered by the almost total destruction of the works of the pre-Socratic philosopher-scientists.

Note to page 55. – I have allowed the traditional rendering of *clepsydra* as 'water-clock' to stand in my text. But Hugh Last (*Classical Quarterly*, xviii) has proved to my satisfaction that the device referred to by Empedocles was not the water-clock, which might hold gallons, but the 'toddy-lifter,' – a household vessel of small dimensions.

CHAPTER FIVE

Hippocratic Medicine – The Cook and the Doctor – The Emergence of the Idea of Positive Science – Science in the Service of Mankind – Limitations of Hippocratic Medicine

WE HAVE spoken in the last chapter of the almost total destruction of the record of Greek science before Socrates. Only for one department of early science has exception to be made. We are fortunate enough to possess a collection of medical writings the oldest of which belong to the beginning of the fifth century. Several different schools are represented in the collection. Nevertheless the collection has come down to us under the name of one, the Hippocratic. It is possible that it formed originally the library of the Hippocratic school in the island of Cos. It owes its preservation to the famous library of Alexandria, founded in the third century, where manuscripts were copied, corrected, and kept. There the collection was put together in its present state, and its fortunate preservation enables us to form a good idea of the progress of medical science in the Greek world during the two preceding centuries. Not all the treatises in the collection are of equal value, but the best of them show a fine blend of science and humanity, while two or three are among the highest products of Greek culture.

The origins of Greek medicine are generally sought by historians in three sources – the old temple practice of Asclepius, the God of Healing; the physiological opinions of the philosophers; and the practice of the superintendents of gymnasia. It is probable that the first of these sources is to be

rejected. 'Arts are not learned,' says Withington, 'in temples by observing real or supposed supernatural intervention, but, as the Hippocratic writers tell us, by experience and the application of reason to the nature of men and things.'* With this opinion of Withington's the author of this book is in complete agreement. He would, however, add that, if we need to supply, as a source of medicine, a substitute for the priest, whom we have rejected, we might find him in the cook.

This, at any rate, was the opinion of one of the greatest of Greek scientists, the unknown author of the Hippocratic tract *On Ancient Medicine*, which belongs to the middle of the fifth century. The treatise is, perhaps, the most important of the whole collection. The author, whoever he was, deserves to be quoted at length. 'The fact is,' he writes, 'that sheer necessity has caused men to seek and to find medicine, because sick men did not, and do not, profit by the same regimen as men do in health. To trace the matter yet further back, I hold that not even the mode of living and nourishment enjoyed at the present time by men in health would have been discovered, had a man been satisfied with the same food and drink as satisfy an ox, a horse, and every animal save man, I mean the raw products of the earth – fruits, leaves, and grass. For on these cattle feed, grow, and live without distress, not needing any other diet. And indeed I believe that to begin with men used the same food. Our present ways of living have, I think, been discovered and elaborated during a long period of time. For many and terrible were the sufferings of men from strong and brutish living when they partook of crude foods, uncompounded and possessing strong qualities – the same in fact as men would

*See his brilliant article, *The Asclepiadae and the Priests of Asclepius*, in Singer's *Studies in the History and Method of Science*, vol. ii, pp. 192–205.

suffer at the present day, falling into violent pains and diseases quickly followed by death. Formerly indeed they probably suffered less, because they were used to it, but they suffered severely even then. The majority naturally perished, having too weak a constitution, while the stronger resisted longer, just as at the present time some men easily deal with strong foods, while others do so only with many severe pains. For this reason the ancients seem to me to have sought for nourishment that harmonised with their constitution, and to have discovered that which we use now. So from wheat, by winnowing, grinding, sifting, steeping, kneading, and baking it, they produced bread, and from barley they produced cake. Experimenting with food they boiled or baked, they mixed and mingled, putting strong pure foods with weaker, until they adapted them to the power and constitution of man. For they thought that from foods which are too strong for the human constitution to assimilate will come pain, disease and death, while from such as can be assimilated will come nourishment, growth and health. To this discovery and research what juster or more appropriate name could be given than medicine, seeing that it has been discovered with a view to the health, well-being and nourishment of man, in place of that mode of living from which came the pain, disease and death?'

I have given this quotation at length so that readers might have the chance to appreciate its remarkable historical insight, its combination of richness of ideas with close attention to fact, and its clear realization of the unbroken development of medical science from the oldest and humblest of the techniques. It is noteworthy that the author of this brilliant scientific work loves to call himself by the name of worker, craftsman, technician. It is because he sees his origin in the cook that he describes his Art as ancient.

By the dialect which he employs the author betrays that he was an Ionian Greek. Medicine, no doubt, like other practices, first became scientific in Ionia. But now, in the fifth century, there were rival medical schools in the West which did not possess the same understanding of medicine as originating in a technique, but sought to deduce the rules of medical practice from *à priori* cosmological opinions. It was to combat this new 'philosophical' medicine that the treatise we are discussing was written.

One of the western schools was at Croton, and its founder was possibly the Pythagorean Alcmaeon whose researches on the sense-organs we have already mentioned. After him, if he was the founder of the school, the standard of Pythagorean medicine declined. Observation dwindled, speculation increased. Philolaus of Tarentum, who lived towards the end of the fifth century, and whose panegyric on the decad we have already quoted, shows the new trend. His opinions are not without interest, but they concern philosophy rather than the healing art. The Pythagoreans attached special importance to the number four. Philolaus decided that there were four principal organs in the human body. His choice of the organs, as well as their number, was determined by considerations of a philosophical order. As all living things have the power of reproduction, he included the organs of sex. Then, following a classification of living things into plants, which have only the power of growth, animals, which add sensation, and men, who alone have reason, Philolaus chose, as the other principal organs, the navel, the seat of the vegetable life, to link men with the plants; the heart, the seat of sensation, to link man with the animals; and the brain, the seat of the reason, which set men above the rest. This somewhat arbitrary scheme is intended to assign man his place in nature's plan; and the choice of the principal organs

is determined by this philosophical purpose. From the point of view of the practical healer it might have been more helpful to assign a less important place to the umbilicus and say something more about the liver and the lungs. Or, if that is to ask too much of an ancient doctor, at least it must be observed that, if the philosopher had not forgotten the connection between the doctor and the cook, he could not have overlooked the stomach!

But it was in the school of Empedocles at Agrigentum that cosmology produced its worst effects on the healing art. There man, like everything else, was supposed to consist of the four elements. The doctrine of the elements included a theory as to their characteristic qualities. Earth was said to be Cold and Dry; Air, Hot and Wet; Water, Cold and Wet; Fire, Hot and Dry. The distemperature of man's body, like the distemperature of nature, was ascribed to the excess or defect of one or other of these qualities. Fever was to be interpreted as an excess of the Hot, a chill as an excess of Cold. This being so, what remedies would a physician who was also a philosopher suggest? Would he not recommend a dose of the Hot to cure a chill and of the Cold to cure a fever?

When the new-fangled doctrines of the western philosophical schools began to be spoken of in his beloved Ionia, anger seized the heart of the author of *Ancient Medicine*. In his opening sentence he leaps to the attack. 'All who attempt to discuss the art of healing on the basis of a postulate – heat, cold, moisture, dryness, or anything else they fancy – thus narrowing down the causes of disease and death among men to one or two postulates, are not only obviously wrong, but are especially to be blamed because they are wrong in what is an art or technique (*technè*), and one moreover which all men use at the crises of life, highly honouring the practitioners and craftsmen in this art, if they are good.'

Into this first sentence our author has managed to pack four separate objections to the new trend in medicine. As they are all of great significance in the history of science, it will be well for us to pick them out and discuss them one by one.

First he objects to the basing of medicine on postulates. The effect of this objection is to separate medicine as a positive science, depending on observation and experiment, from cosmology where experimental control was not possible in antiquity. We proceed to quote his own words: 'Postulates are admissible in dealing with insoluble mysteries; for example, things in the sky or below the earth. If a man were to pronounce on them neither he himself nor any of his audience could tell whether he was speaking the truth. *For there is no test the application of which would give certainty.* But medicine has long had all its means to hand, and has discovered both a principle and a method, through which the discoveries made over a long period are many and excellent, and through which full discovery will be made, if the enquirer be competent, conduct his researches with knowledge of the discoveries already made, and make them his starting-point.'

Secondly, he protests that the new-fangled doctors are 'narrowing down the causes of death and disease'. This is most remarkable. It is a protest by a practising technician, conscious of the richness of his positive science, against the barrenness of metaphysics. The historical significance of this is very great. The technician is appalled at the ignorance of the philosophers. Art had not yet been made tongue-tied by authority. For the Hippocratic doctor the qualities of things which affect a man's health were not three or four. They were infinitely various. 'I know,' he protests, 'that it makes a difference to a man's body whether bread be of bolted or unbolted flour, whether it be of winnowed or un-

winnowed wheat, whether it be kneaded with much or little water, whether it be thoroughly kneaded or unkneaded, whether it be thoroughly baked or underbaked, and there are countless other differences. The same applies to barley. The properties of every variety of grain are powerful and no one is like another. But how could he who has not considered these truths, or who considers them without learning, know anything about human ailments? For each of these differences produces in a human being an effect and a change of one sort or another and upon these differences is based all the dieting of a man, whether he be in health, convalescent or ill.' Then he proceeds to supplement the handful of Empedoclean concepts with a list of others more relevant to medical science – in foods, such qualities as sweetness, bitterness, acidity, saltness, insipidity, astringency; in human anatomy, the shapes of the organs; in human physiology, the capacity of the organism to react to an external stimulus. Thus does the cook rebuke the cosmologist.

The third reason for his anger is, not that the philosopher should be wrong, but that he should be wrong in a technique or art (*technè*). The reason why ignorance in respect of a *technè* is inexcusable is, that no knowledge was worthy to be called a *technè* unless it gave results. Here the justifiable pride of the craftsman is noticeable; and it admonishes us that the test of early science was, not the laboratory, but practice. We must not overlook this fact when we debate the point, whether Greek science knew experiment or not. A technique was a mode of imitating nature. If it worked, that was proof that the technician understood nature.

The fourth reason for his anger with the doctor who possesses only philosophical postulates but is ignorant of the art is that it is the patient who suffers. This concern for the patient is specially characteristic of the Hippocratic doctors.

They were severely scientific at their best, but at their best they also maintained that the first duty of the doctor is to heal the sick rather than to study disease. In this there was a certain measure of disagreement between them and the neighbouring school at Cnidus. We might express the difference by saying that the ideal of the men of Cnidus was science, that of the men of Cos science in the service of humanity.

We have now listed the four chief objections of our practising physician to the medical innovations of the philosophers. At this early date, before much positive knowledge had accumulated, and before specialization had in consequence become necessary, it was natural that a philosopher should embrace every branch of knowledge. There is nothing therefore surprising in Empedocles turning his attention to medicine. But his doing so brought sharply into view the fact that there was a kind of speculation that was admissible in cosmology but inadmissible in medicine. Cosmologists tended to start from some observation, or some few observations (change of water into ice or steam; the mathematical relation between the lengths of vibrating strings; the transmutation of food into flesh), and then elaborate on this slender foundation a theory of the universe, satisfied if the system they evolved hung together with reasonable logic. But this could not satisfy the doctor, whose theories were continually tested in practice, proved right or wrong by their effect on the patient. A stricter conception of the scientific method was formed. It can truly be said that the Hippocratic doctors at their best advanced fully to the idea of a positive science. What differentiated their science from ours was less the failure to realize the importance of experiment than the absence of instruments of exact measurement and of any technique of chemical analysis. They were as scientific as the

material conditions of their time permitted. This statement we proceed to justify by a few quotations.

Our first quotation is again from the author of *Ancient Medicine*. In it he claims that the method of observation and experiment practised by the doctors, and not the *à priori* method of the cosmologists, is the only way to find out about the nature of man. 'Certain physicians and philosophers assert that nobody can know medicine who is ignorant what man is: he who would treat his patients properly must, they say, learn this. But the question they raise is one for philosophy; it is the province of those who, like Empedocles, have written on natural science, what man is from the beginning, how he came into being at first, and from what elements he was originally constructed. But my view is, first, that all that philosophers or physicians have said or written on natural science pertains less to medicine than to literature. I also hold that clear knowledge about the nature of man can be acquired from medicine and from no other source, and that one can attain this knowledge when medicine itself has been properly comprehended, but till then it is impossible – I mean to possess this information, what man is, by what causes he is made, and similar points accurately' (*Ancient Medicine*, chap. xx).

Our next quotation concerns the correct use of inference where facts are involved which are not directly accessible to sense. The writer is discussing the difficulty of treating internal complaints. 'Without doubt no man who sees only with his eyes can know anything of what has been here described. It is for this reason that I have called these points obscure, even as they have been judged to be by the art. Their obscurity, however, does not mean that they are our masters, but as far as is possible they have been mastered, a possibility limited only by the capacity of the sick to be

examined and of researchers to conduct research. More pains, in fact, and quite as much time, are required to know them as if they were seen by the eyes; *for what escapes the eyesight is mastered by the eye of the mind*, and the sufferings of patients due to their not being quickly observed are the fault, not of the medical attendant, but of the nature of the patient and of the disease. *The attendant in fact, as he could neither see the trouble with his eyes nor learn it with his ears, tried to track it by reasoning*' (*The Art*, chap. xi). The reader will not fail to observe that what the Hippocratic doctor meant by 'the eye of the mind' was something very different from what Plato meant when he used the same phrase. Plato meant deduction from *à priori* premises. The Hippocratic writer meant the inferring of invisible facts from visible symptoms.

Our third quotation enumerates some of the devices employed to get at the hidden secrets of the body. 'Now medicine, being prevented, in cases of empyemas, and of diseased liver, kidneys, and the cavities generally, from seeing with the sight with which all men see everything most perfectly, has nevertheless discovered other means to help it. There is clearness or roughness of the voice, rapidity or slowness of respiration, and the character of the customary discharges: sometimes smell, sometimes colour, sometimes thinness or thickness furnishing medicine with the means of inferring what condition these symptoms indicate. Some symptoms indicate that a part is already affected, others that a part may be thereafter affected. When this information is not afforded, and nature herself will yield nothing of her own accord, medicine has found means of compulsion, whereby nature is constrained, without being harmed, to give up her secrets; when these are given up she makes clear to those who understand the art what course ought to be pursued. The art, for example, forces nature to disperse phlegm by acrid foods

and drinks, so that it may form a conclusion by vision concerning those things which were before invisible. Again, when respiration is symptomatic, by making patients run uphill it compels nature to reveal symptoms' (*The Art*, chap. xiii).

Our last quotation shows the physician attempting to sketch a theory of cognition. 'One must attend in medical practice not primarily to plausible theories, but to experience combined with reason. A true theory is a composite memory of things apprehended with sense-perception. For the sense-perception, coming first in experience and conveying to the intellect the things subjected to it, is clearly imaged, and the intellect, receiving these things many times, noting the occasion, the time and the manner, stores them up in itself and remembers. *Now I approve of theorising if it lays its foundation in incident, and deduces its conclusions in accordance with phenomena.* For if theorising lays its foundation in clear fact, it is found to exist in the domain of intellect, which itself receives all its impressions from other sources. So we must conceive of our nature as being stirred and instructed under compulsion by the great variety of things; and the intellect, as I have said, taking over from nature the impressions, leads us afterwards to the truth. *But if it begins, not from a clear impression, but from a plausible fiction, it often induces a grievous and troublesome condition. All who act so are lost in a blind alley*' (*Precepts*, chap. i).

These quotations should serve to make clear the extent to which the ancient doctors had advanced to the modern conception of a positive science. They also throw some light on the question of the debt of Greek medicine to the philosophers, the second source usually mentioned by historians. When we have in mind the tendency of the philosophers to foist on to medicine the *à priori* methods of cosmology, then we are inclined to feel that Hippocratic medicine owed as

little to the philosophers as to the priests. On the other hand, when we consider the contribution of an Empedocles or an Anaxagoras to the problem of the correct use of sense-evidence, we see that their opinion on this point was identical with that of the doctors. Furthermore, it was not altogether bad for medicine that it should become a subject of discussion among the philosophers. A science can suffer if it becomes divorced from the general intellectual life of the age, and the philosophers acted as something of a clearing-house of ideas, and contributed to the formation of a systematic body of medical theory which, even if premature, fed a natural impatience with the belief that the slow progress of scientific investigation had reached its goal. In very truth, life is short and art is long, and premature generalisation is sometimes better than none at all.

The third tributary to the stream of Greek medicine usually mentioned in the books is that which flowed from the directors of the gymnasia. They possessed a wonderfully accurate knowledge of surface anatomy, developed a sound technique of handling dislocations, and in their general concern for the preservation as well as the restoration of the health of their patrons, paid attention to massage, diet, and graduated systems of exercise. This is a genuine contribution, so far as it went, and the most important of the three sources discussed by the historians. It is not out of contempt for it that we pass it by to deal with the major failure of Greek medicine which this topic inevitably suggests. For the gymnasia were the haunts of the citizen, and of the better-class citizen at that. They provided the opportunity for members of the leisured class to submit themselves, under expert direction, to regimens of health. But the question we now wish to enquire into is the health of the workers.

We have already quoted a passage from Xenophon which

says: 'What are called the mechanical arts carry a social stigma and are rightly dishonoured in our cities. For these arts damage the bodies of those who work at them or supervise them, by compelling the workers to a sedentary life and to an indoor life, by compelling them, indeed, in some cases to spend the whole day by the fire.' Now it is certain that these workers, with their damaged bodies, did not form the clientèle of the directors of the gymnasia, and, conversely, that the contribution the directors made to medicine was not intended, nor adapted, to the needs of the workers. Indeed, it is clear that, as society developed more and more in the direction of making a sharp cleavage between the categories of citizen and worker, medicine tended more and more to become a service directed to the needs of a leisured class. This produced a very paradoxical result.

One of the glories of Hippocratic medicine is that it endeavoured always to see man in relation to his environment. The treatise *Airs Waters Places* is a pioneer work in its clear-cut conception of the effect upon the human constitution not only of man's natural, but of his political environment. The Hippocratic doctor took into consideration the food a man ate, the kind of water he drank, the climate he lived in, and the effect on him of Greek freedom or Oriental despotism. But there is no aspect of a man's environment that affects him more intimately or more constantly than his daily occupation, and on this subject the Hippocratic treatises are dumb. The study of occupational diseases did not begin till quite recent times – with Paracelsus (*c.* 1490–1541) and, still more important, Ramazzini (1633–1714).

CHAPTER SIX

Before and After Socrates – The First Science of Society – The Sophists – The Socratic Revolution in Thought

WE HAVE now completed our survey of the chief figures in the first age of Greek science, the Heroic Age, which runs from Thales to Democritus. Philosophers call this the pre-Socratic Age, and it has been common with historians to regard this age as having been mainly concerned with bold, but unfounded, speculation on 'things in the heavens'. A story, meant to be symbolical, was current in antiquity that Thales, walking absent-mindedly through the town of Miletus, had fallen into a well. His preoccupation with the 'things above' had made him neglect what was at his feet. Such was the inevitable consequence of the impious attempt to establish a philosophy of nature. From this false start mankind was rescued, according to this view of the history of thought, by the great Athenian moralist, Socrates. He 'brought philosophy down from heaven to earth'. He insisted that the proper study of mankind is man. He diverted attention from physics to ethics. Under his influence philosophy abandoned its presumptuous attempt to understand the heavens and turned to the humbler task of teaching men how to behave as men.

This account of the relationship of Socrates to his predecessors is, in our view, false. The older natural philosophers did not concentrate on speculation about the things in the heavens to the neglect of human affairs. On the contrary, the original and characteristic thing about the Ionian way of

thought was that it recognized no ultimate distinction between heaven and earth, that it sought to explain the mysteries of the universe in terms of familiar things. To be precise, the source from which Ionian philosophy sprang was the new outlook on the world resulting from the control over nature exercised by the technician who was also an honoured member of a free society. A technique was a way of helping oneself by imitating nature. It was the success with which he applied his techniques that gave the Ionian natural philosopher his confidence that he understood the workings of nature. The belief in the identity of natural and technical processes is the clue to the mentality of the period.

The sixth and fifth centuries, the period known as that of pre-Socratic philosophy or as the Heroic Age of Science, are characterized not only by a development of abstract thought. They were also a time of great technical progress, and what is new and characteristic in their mode of thoughts is derived from the techniques. Technical development was the magic wand which was changing the old form of society based mainly on the land into a new form of society based largely on manufacture. Technical progress was calling into existence a new class of manufacturers and merchants which quickly assumed political control in the cities. In the first decade of the sixth century, Solon, who represented the new class, attempted to modernize Athens, the old Athens torn with the strife between landlord and peasant. In order to achieve this, Solon, we are told by Plutarch, 'invested the crafts with honour'. He 'turned the attention of the citizens to arts and crafts, and made a law that a son need not support his father in old age unless the father had taught him a trade'. 'At that time,' says Plutarch, 'work was no disgrace, nor did the possession of a trade imply social inferiority.' The men then honoured were men like Anacharsis the Scythian, whose

titles to glory were that he had improved the anchor and invented the bellows and the potter's wheel. Or men like Glaucus of Chios, the inventor of the soldering-iron; or Theodorus of Samos, who was credited with a long list of technical inventions – the level, the square, the lathe, the rule, the key, and the method of casting bronze. These navigational and industrial achievements were appreciated by the merchants of Miletus, among others. Their growing prosperity depended on manufacture for export. It was among them that Thales applied his skill in mathematics and geometry to the improvement of the art of navigation. It was for them that Anaximander made the first map of the world. It was there that the world began to be thought of as a machine. The temper of the age was such that honour was still given to the technician. The Greek word for wisdom, *sophia*, still meant at this time technical skill, not abstract speculation. Or rather the distinction between the two was not forced, for the best speculation was based on technical skill. The author of *Ancient Medicine* knows no higher title than technician. It is in this context that the natural philosophy of the Ionians was born. To represent it as wholly absorbed in speculation on the heavens to the neglect of human interests is false.

But the ripest product of this new outlook is still to be mentioned. In the free cities of old Ionia the conquest of nature through techniques gave birth to the ambition of extending the domain of reason over the whole of nature, including life and man. There was a definite and conscious movement of rational thought over the whole sphere of existence. There was a propaganda of enlightenment, as many pages in the Hippocratic writings show. 'It seems to me,' says one writer, dealing with the mysterious affliction epilepsy, 'that the disease is no more divine than any other. It has a

natural cause, just as other diseases have. Men think it divine merely because they do not understand it. But if they called everything divine which they do not understand, why, there would be no end of divine things.' These are truly classical words. They mark the advent of a new epoch in human culture. In their gentle irony they pronounce final judgment on a past age, on the period of mythological explanation. True, their point of view has not yet prevailed everywhere on earth. The battle is still joined and the issue doubtful. Miracles are still the basis of the world-view of large sections even of civilized mankind. Christendom has not yet made up its mind to accept a strictly naturalistic history of Christianity, or even, for that matter, of Joan of Arc. But the old Ionian formulation remains to do its silent work in the mind of civilized man. 'Men think it divine merely because they do not understand it. But if they called everything divine which they do not understand, why, there would be no end of divine things.' The identification of the divine with the not-yet-explained was the shrewdest of blows for reason and nature.

The movement of enlightenment which has left its mark on the Hippocratic writings produced also a sketch of the rise of human culture, which is a contribution of the Ionian school to science of absolutely first-class importance.*

'At the time of the original constitution of the universe,' runs the text, 'heaven and earth had but one form, their elements being mixed together. Then their substances

*This sketch survives in the history of Diodorus Siculus, Bk. I, chaps. vii and viii. Its attribution to Democritus was plausibly suggested by K. Reinhardt (*Hermes*, Band 47, pp. 492 ff.), but this attribution is contested by others on the ground that the sketch contains no clear reference to atomism. It may well be pre-atomic. The point is immaterial to our argument.

separated, and the cosmos completely assumed the order we now observe in it, but the Air continued in a state of agitation. As a result of this movement, the fiery portion of the Air collected in the upper spaces, its nature tending to rise on account of its lightness, and for this reason the sun and all the rest of the heavenly bodies were caught up in the general rotatory movement. The more dense and turbid portion of the Air joined the moist element and settled into the same region with it by reason of its weight. When this heavier matter had long crowded and revolved upon itself, it formed the sea out of its moist elements and the earth out of its more solid elements.

'The earth at first was muddy and quite soft. It was only owing to the action of the sun's heat that the earth began to harden. Then, on account of the heat, some of the moist elements swelled and the earth began to bubble up at many places. At these places there formed fermentations enclosed in delicate membranes, a phenomenon still to be observed in marshes and bogs when a rapid rise in the temperature of the air supervenes suddenly on a chilling of the earth. In this manner, through the action of the heat, the moist elements began to produce life. The embryos thus formed got their nourishment at night from the mist which fell from the surrounding air, while by day the action of the sun's heat imparted firmness. At the end of this stage, when the embryos had got their full development and the membranes had been dried up by the heat and had burst, all sorts of living things came forth. Of these, those which had the largest share of heat went off to the upper regions and became birds; those which had a greater admixture of earth formed the class of creeping things and other land animals; while those which had more of the moist element went off to the region akin to them and became what we call fish. But the continu-

ing action of the sun and wind hardened the earth still more, until it was no longer able to bring to life any of the larger creatures, but each of the larger living things was reproduced through intercourse of like with like.

'The first men lived a random life like wild animals, going out to pasture independently of one another, moving towards whatever vegetation attracted them and to the uncultivated fruits of the trees. It was expediency that taught them to co-operate because individuals became the prey of wild beasts. It was only when fear brought them together that they slowly arrived at mutual recognition of their common form. Their utterance was at first confused and without significance. It was only gradually that they became articulate, agreed on conventional sounds for each object, and made their discourse on every topic mutually intelligible.

'Groups like this formed over the whole habitable earth; but they did not all use the same forms of speech, for each group had determined their locutions as chance decided. Accordingly all sorts of languages came into existence. The first groups of men to be constituted became parents of all the races of mankind. Since none of the conveniences of life had been discovered, the first men lived a burdensome life. They were without any clothing, unacquainted with houses or fire, and had no idea at all of cultivated foods. Even the idea of making a store of wild foods had not occurred to them and they made no provision against want. The result was that they died in great numbers during the winters through cold and lack of nourishment. Gradually, however, learning from experience, they began to take refuge in caves during the winter, and to store such fruits as admitted of being kept. Then fire and other conveniences were discovered, and the arts and all the things that promote social life were invented. The general law of the process is that it is necessity that

teaches man everything. Necessity is the intimate guide who conducts man through every lesson, and necessity has in man a naturally apt pupil, equipped as he is with hands, speech, and mother-wit for every purpose.'

Diodorus, who has preserved for us this summary sketch of the history of man and society, was, as we know from a careful study of his book, not the most intelligent of men. It is unlikely that he has done full justice to the thought of his original. But enough remains to be extraordinarily impressive. The writer, it appears, had a dialectical concept of the evolutionary process. Under certain historical conditions he imagines that new forms of existence can arise. At a certain stage of its development the earth is able to produce living organisms. When this stage passes, spontaneous generation is succeeded, at least for the larger creatures, by sexual generation. The process of evolution combines quantitative development with qualitative leaps. Further, this dialectical process is applied not only to the origin and development of life, but to the origin and development of society. Man is not by nature a political animal. He *becomes* a political animal by a gradual process of experience, since only those men who learn to co-operate escape destruction by wild beasts. Man is not divinely endowed with the gift of speech. He becomes a talking animal by a process of historical development. The meanings of words are conventional. Instead, therefore, of endeavouring to understand nature by examining the meanings of words – a procedure which later became the characteristic vice of Greek thought – the writer was for understanding the meanings of words by the study of social history. Man is not by definition, and in his essential nature, a rational animal. He becomes a rational animal through a rigorous schooling by necessity, and largely because he is possessed of a capable pair of hands. The writer recognized

the importance of the techniques in the history of human culture. He makes clear that man outdistanced the other animals in the race for survival by his superior teachability. From other sources we learn that Democritus, who may be the author, thought that man had got the hint for weaving from the spider, and for architecture from the swallow, and that it was by imitating the birds that he had learned to sing.

The influence throughout Greek lands of the new modes of thought which had been fashioned and published by such men as Anaximander, Empedocles, Anaxagoras, and Democritus is not easy to assess accurately. There is no doubt that it was great. Anaxagoras, a native of Clazomenae, was brought to Athens by Pericles to spread the new knowledge. Another distinguished foreigner who spent much of his life at Athens was Protagoras of Abdera. He is the first example we have had occasion to mention of a new class of man, the Sophist, characteristic of this time. The sophists were itinerant lecturers who went from town to town spreading the new ideas. They specialized in history and politics, and professed to be able to teach the art of government. There is little room to doubt that the general background of their ideas on society was that of the sketch by the unknown writer we have just quoted. Plato, who was diametrically opposed to this theory of the origin and nature of civilization, singled out the opinions of the Sophists, and their manner of life, for attack.

The three most distinguished of the Sophists were the Protagoras already mentioned (who came from the same town as Democritus – Abdera seems to have been a most enlightened place), Gorgias, of Leontini in Sicily, and Hippias, of Elis in the Peloponnese. Plato has given them a bad name, and much that has survived about them is de-

signed to illustrate the irresponsibility of their teachings and the vulgarity of their self-advertisement. It is doubtful if these criticisms are well-founded. Protagoras said: *Man is the measure of all things.* For this he figures in the history of philosophy as the representative of the principle of subjectivity in its most extreme form. Gorgias said: *There is no truth; if there were, it could not be known; if known, it could not be communicated.* He has become the type of the sceptic. Hippias, who has the reputation of a braggart, distinguished himself by attending the games at Olympia in festive attire, every particle of which had been made by his own hands, and professing himself ready to lecture on any subject from astronomy to ancient history. Subjectivity, scepticism, and boastfulness, not to mention love of gain, such were the vices of the sophists from which Socrates, according to Plato, rescued Greek thought by the example of his life and conversation.

It can be no part of a short history of Greek science to enter upon the discussion of the philosophical issues raised by the Platonic attack upon the Sophists. But from the point of view of the historian of science a few words must be said about each of the three. With regard to the first, Protagoras, it is extremely doubtful whether the saying attributed to him is correctly interpreted as an uncompromising assertion of the principle of subjectivity. Protagoras was a legislator. At the request of Pericles he made a constitution for the famous colony of Thurii in South Italy, a progressive community which believed in planning and employed the Pythagorean architect, Hippodamus of Miletus, to build them a model town. The enlightened legislator for this community regarded laws as a human creation. He had much the same view of the evolution of human society as his fellow-townsman, Democritus. He believed, like the Ionian philosophers

generally, in the contractual view of justice. When he said that man was the measure of all things, he almost certainly meant that human institutions should be adapted to suit changing human requirements. But this idea was anathema to Plato, who, through the mouth of Socrates in his *Republic*, taught that the Idea of Justice was eternal and was to be understood not through the study of history but by pure reason. This, and not the principle of subjectivity, would appear to be the real ground of difference between Protagoras and the Platonic Socrates.

How the saying of Gorgias is to be interpreted is unsure. Let us take it at its face value as an expression of extreme scepticism. As such it can in no sense be regarded as the product of Ionian materialism. The natural philosophy of the Ionians provides a much better answer to such scepticism than the Ideal theory of the Platonic Socrates. The authors of the Hippocratic treatises were convinced that truth exists, that truth can be known, and that truth can be communicated. So were Empedocles, Anaxagoras, and Democritus. The tradition of science they built up is the only way to establish the objectivity of truth. It was the Platonic schools which later drifted into a scepticism which might very aptly be summed up in the formula of Gorgias. To this day it is the Platonic philosophy, not the scientific tradition, which is the breeding-ground of scepticism.

As for Hippias, arrayed entirely in articles of his own making down to the ring on his finger, he is a perfect illustration of the fact that the older tradition of wisdom included the techniques. A spinner, weaver, tanner, tailor, cobbler, and smith, all in his own person, he is typical of the older generation of wise men whose title to wisdom was not compromised by the ability and readiness to use their hands. He was prepared, we are told, to lecture on ancient history.

Nothing is more certain that that his conception of history gave recognition to the crafts as a factor in human development.

If we sum up the evidence given in this chapter, we see that it is quite inadequate to describe the older philosophers as dreamers about the things in heaven to the detriment of their understanding of human affairs. It follows that it cannot be correct to describe the Socratic revolution in thought as consisting essentially in his having brought philosophy down from heaven to earth. It would be more in accordance with the evidence to state the matter thus. The Ionian school of natural philosophers had offered a materialistic explanation of the evolution of the cosmos, they inculcated the ideal of positive science and the reign of universal law, they gave an account of the development of civilization in which man, through his conquest of techniques, figured as the author of his own progress, they supported the contractual theory of justice. Socrates, on the other hand, discouraged research into nature, substituted for the ideal of positive science a theory of Ideas closely linked with a belief in the Soul as an immortal being temporarily inhabiting a house of clay, sought to explain nature teleologically and human history providentially, and regarded Justice as an eternal idea independent of time, place, and circumstance. In a word, Socrates abandoned the scientific view of nature and man, which had been developed by the thinkers of the Ionian school from Thales to Democritus, and substituted for it a development of the religious view which had come down from Pythagoras and Parmenides. He did not so much bring philosophy down from heaven to earth as devote himself to persuading men that they must so live on earth that when they died their souls would return at once to heaven. It is likely that he made important contributions to logic. Aristotle

credits him with introducing Induction and Definition. But his mastery of these arts was displayed solely in the sphere of ethics and politics, and, at that, was metaphysical rather than historical in character. He made no contribution to science.

CHAPTER SEVEN

Plato – The Platonic Attitude to Natural Philosophy – Theological Astronomy – The Eye of the Soul and the Eye of the Body – Philosophy and Techniques

APART from the Hippocratic Corpus we have no complete works of Greek philosophy or science extant before Plato, and none of the Hippocratic writings can be assigned with absolute certainty to any particular author. Of Plato we not only have complete works extant, we have all his published work. He is thus the first philosopher about whose opinions we are adequately informed. True, the record of his oral instruction in the Academy has not survived, but none of his dialogues has perished. About thirty of the dialogues ascribed to him are accepted as genuine. They constitute a great bulk of writing, roughly equal to the Bible in size. The largest of them, the *Republic* and the *Laws*, are in ten and twelve books respectively.

The *Republic*, written in his forties, and the *Laws*, lacking only its final polish when he died in his eighty-first year, dominate the whole collection. The first attempts to sketch an ideal society; the second resumes the same theme in a more practical spirit and in the light of greater experience; together they inform us of what was the major effort of his life, the regeneration of the political life of Greece. The Academy was founded for the same purpose, to train a new type of citizen of the ruling class, who was not to remain in the Academy, but go back to public life. This attempt to reform public life by the training of a new type of individual was, like the general trend of his philosophy, Pythagorean.

The only important prose which had been written in Athens before Plato was history. The implicit purpose of Herodotus, the explicitly avowed purpose of Thucydides, was so to present the record of the past that it might serve to guide men's actions in the future. Historians, respectively, of the rise and fall of Athenian democracy, they sought to make their public conscious of the drama of Greek civilization in which Athens had played the leading part. History with them was the school of politics. Their temper was objective, like that of the Ionian Natural Philosophers to whose movement they essentially belong. They sought the law of the development of human society, as the philosophers had sought the law of the development of nature. There is the closest resemblance in world outlook between Thucydides, Democritus, and the best writers in the Hippocratic Corpus. An idea common to all is that, as men are products of nature, so their characters are products of their society. Thucydides paints a terrifying picture of the moral degeneration of Greece during the Peloponnesian War. The degeneration of the individual is the *consequence*, not the *cause*, of the war.

With Plato the emphasis shifts to the individual soul. Wars, external and internecine, are the product of the individual man's unruly desires (*Phaedo* 66c). 'The *Republic*,' says Professor A. E. Taylor, 'which opens with an old man's remarks about approaching death and apprehension of what may come after death, and ends with a myth of judgment, has all through for its central theme a question more intimate than that of the best form of government or the most eugenic form of propagation; its question is, How does a man attain or forfeit eternal salvation?' The heart of Plato's thought is a doctrine of the immortality of the soul which he shares with the Pythagoreans. Man's soul becomes the field on which the battle between good and evil is fought out, and the battle,

at the same time, takes on a transcendental significance, for man's soul is not a part of nature, but a visitor from a celestial realm. This individual salvation will not be effected by public policies nourished on a study of history, but by arriving at an understanding of the eternal values: Truth, Beauty, and Goodness. The path to this understanding lies through mathematics and dialectics. Over the door of his Academy Plato had written up: *You cannot enter here unless you know geometry*. When the great moment of his life came and he was invited to assist in the government of Syracuse, the most powerful city at that time in the Greek world, Plato's appreciation of this opportunity was shown by the use he made of it. He began to teach the young prince who had invited him geometry. Thus early did the word *academic* merit its present significance.

The mere bulk of his writings, surviving in the midst of the general wreck, would suffice to give Plato, in the eyes of modern students of antiquity, a unique importance. To this must be added their superb artistry. Being endowed with dramatic gifts that matched his discursive powers, Plato cast his thoughts into the form of dialogues. Here, grouped generally round the central figure of Socrates, he brought upon the scene his sophists, generals, statesmen, artists, and others, and made them talk. If the disquisitions are sometimes tedious and arbitrary as well as profound, they are set off with a golden eloquence to which wit, irony, imagination, passion alike contribute. Furthermore, these writings are preserved to us with a textual purity, due mainly, no doubt, to the fact that the Academy enjoyed as an institution an uninterrupted life of some nine hundred years, which is unique in the record of ancient literature. The student who masters his idiom can enter, with a fullness of knowledge rarely paralleled until modern times, into the life of the

Athens that was the school of Hellas then and has since become the school of mankind.

For these reasons, and many more, the Platonic writings have long attracted, and still attract, a degree of attention which the earlier philosophers and sophists cannot claim. But the great prestige of his writings constitutes a difficulty for the historian of science. Plato wrote much about those problems of epistemology which lie on the border between philosophy and science. There is no doubt about his eminence as a philosopher. His contribution to science is, however, open to question. Does he deserve the same place in the history of science which by universal accord he holds in philosophy?

Science before Plato had achieved remarkable advances which we may roughly classify under three heads. The first and decisive step, which we associate especially with the Milesians, was the new attitude of attempting to explain the phenomena of nature, including human nature, without supernatural intervention. Secondly, we find that a rudimentary technique of interrogating nature by means of experiments had begun. There was a growing practice of observation and experiments, in Ionia, in Italy, in Sicily, in Athens itself, accompanied, as its philosophical implications became more clearly understood, by a lively debate on the validity of sense-evidence. Thirdly, although the importance of this has been little recognized and the fact has been denied by some, there was the vital connection between natural philosophy and techniques, which determined the character of the early philosophy of nature. In developing his attack on the Ionian philosophers, Plato accords their recognition of this connection an important place in their general world-outlook. The following are the words in which he describes their point of view: 'The arts which make the most serious contribution to human life are those which blend their own

power with that of nature, like medicine, agriculture, and gymnastics' (*Laws*, X, 889d). This plainly implies a philosophy of the techniques, an attempt to define their essential character and to assign them their very important place in the development of civilized society. We shall discuss Plato's attitude to the science of his predecessors under these three heads. First we shall consider his attitude to the naturalism, or atheism, of the Ionians.

When the Ionians began to explain the phenomena of the heavens in naturalistic terms, there can be no doubt either of the novelty of their outlook or of the scandal it caused. The new teaching conflicted not only with vague popular beliefs in the divinity of the heavenly bodies, but with formal theological doctrines inculcating similar views. An effort was made by the Pythagoreans, and later by Plato, to put the supernatural back into astronomy; and, in fact, astronomy did not really make its way with the Greek public until it had been rescued from atheism. This is a typical occurrence in the history of thought. A scientific hypothesis has often failed to gain currency until it has received the stamp of religion. A modern, and more familiar, example will illustrate the phenomenon in question. It is not without its importance for the understanding of the history of science.

'It seems probable to me,' wrote Newton, echoing Gassendi, 'that God in the beginning formed matter in solid, massy, hard, impenetrable particles, of such sizes and figures, and with such other properties, in such proportions to space, as most conduced to the end for which He formed them; and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces: no ordinary power being able to divide what God Himself made one in the first creation.' Here it is obvious that two traditions are

mingled. The atoms, with their various properties, belong to the scientific tradition; they are nothing more or less than the atoms of Democritus. But the atoms, as they left the mind of Democritus, belonged to an atheistic universe which was to be explained entirely by natural law. This had at all times proved an obstacle to their acceptance. Newton, however, wove another tradition in with his account of the atoms. God, the Creation, the end God has in view, and the impossibility of putting asunder that which God has once joined, belong to the religious tradition. The passage then, as it left the pen of Newton, is a strange amalgam of religion and science; and it is to the intimate blend of the two that the success of Newton's views is partly due. The scientific hypothesis would have had little chance of making its way in seventeenth-century Europe if it had clashed violently with the theological fashion of the age. It was therefore altogether fortunate for the success of the Newtonian physics that the author should have been convinced that the atoms of Democritus had been made by God, which was no part of the original conception. Descartes, it may be relevant to recall, had had to hold up his *Principia Philosophiae* for eleven years while he sought a formula by which his unorthodox position might be made to appear acceptable to authority. In the end he did not find one. Newton was more fortunate. In good faith he re-wrote the first verse of the first chapter of *Genesis* in the light of the science of the Greek atomists: *In the beginning God created the atoms and the void.* The English genius for compromise has never been better illustrated.

The atoms had to await the seventeenth century of our era to be baptized into Christianity. Astronomy was Pythagoreanized and Platonized within a few generations of the Ionian dawn. In one of the best text-books of ancient science which has come down to us, an Alexandrian hand-book on astron-

omy by one Geminus, we have this account of the Pythagorean influence on astronomy:

'There underlies the whole science of astronomy,' he writes, 'the assumption that the sun and the moon and the five planets move at even speeds in perfect circles in an opposite direction to the cosmos. It was the Pythagoreans, the first to approach these questions, who laid down the hypothesis of a circular and uniform motion for the sun, moon, and planets. Their view was that, in regard of divine and eternal beings, a supposition of such disorder as that these bodies should move now more quickly and now more slowly, or should even stop, as in what are called the stations of the planets, is inadmissible. Even in the human sphere such irregularity is incompatible with the orderly procedure of a gentleman. And even if the crude necessities of life often impose upon men occasions of haste or loitering, it is not to be supposed that such occasions inhere in the incorruptible nature of the stars. *For this reason they defined their problem as the explanation of the phenomena on the hypothesis of circular and uniform motion.*'

We have already spoken of the blend of science, religion, and politics in Pythagorean thought. It is here illustrated in a topic of major importance for the history of European culture. The application of mathematics to astronomy was a scientific step; the belief that the heavenly bodies are divine belongs to religion; the notion that a gentleman partakes in an especial degree of the characteristics of divinity belongs to class politics, which have throughout the history of civilization been granted a cosmic significance they do not deserve.

> When beggars die there are no comets seen;
> The heavens themselves blaze forth the death of princes.

Not till the time of Kepler did astronomy rid itself of the

necessity of interpreting the behaviour of the planets in terms of the social prejudices of the Pythagoreans.

These politico-religious prejudices remained to trouble the astronomical science of Plato, who felt the scandal of the planets in an especial degree. Plato was the author, or propagator, of an astral theology in which the stars were cast for the rôle of patterns of divine regularity. He found it incompatible with this requirement that, conspicuous among the hosts of heaven, where

> Round the ancient track marched rank on rank
> The army of unalterable law,

should be a parcel of five disorderly vagabonds (the word planet means vagabond in Greek). The inconvenience was especially great inasmuch as the problem of human vagabondage had reached a crisis at this time in Greece.

Plato's contemporary, Isocrates, had made a special study of the problem of these sturdy beggars. The remedy he proposed was not increased production and better distribution of this world's goods. Faced with an ever-increasing throng of roving outcasts, his idea was to enlist them, drill them, and hurl them against the Persian Empire. If they could not conquer it outright, they could at least tear enough off its territory to provide living-space for themselves. The alternative was revolution at home. 'If we cannot check the growing strength of these vagabonds,' wrote Isocrates, 'by providing them with a satisfactory life, before we know where we are they will be so numerous that they will constitute as great a danger to the Greeks as to the barbarians' (*Philip*, 121). Under these circumstances it is not surprising that, as a contribution to the liquidation of vagabondage on earth, Plato should have determined to liquidate it in heaven. He 'set it as a problem to all earnest students to find

"what are the uniform and ordered movements by the assumption of which the apparent movements of the planets can be accounted for".' Until this problem could be solved, his astral theology, by which he set much store in his proposed reconstruction of society, risked total failure. Why worship the stars if these divine beings could do no better than set a conspicuous example of irregularity and disorder? It is altogether false to regard Plato's challenge to the mathematicians to reduce the planets to order as proof of a disinterested love of science. It was not an attempt to find out the facts, but to conjure away socially inconvenient appearances on the basis of any plausible hypothesis.

Plato's disciples were not slow in providing him with the desired solution of his problem. The apparent paths of the planets were analysed, by Eudoxus and Callippus, into the resultants of over thirty circular rotatory movements. On this basis, astronomy, which had before been tainted with atheism, was given citizen rights in Greece. Plutarch, in his *Life of Nicias*, is our informant on this point, the military disaster at Syracuse, brought about by that distinguished general's superstitious dread of eclipses, prompting his biographer to give some account of the progress of astronomical knowledge among the public at large.

'The eclipse frightened Nicias very much, as well as all the others who were ignorant or superstitious enough to mind such things. For though by this time even the masses had accepted the idea that an eclipse of the *sun* towards the end of the month had something to do with the moon, they could by no effort conceive what could get in the way of the *moon* to produce the effect of a full moon suddenly becoming obscured and altered in colour. This they thought uncanny, a sign sent from God to announce some great calamity. Anaxagoras, the first man who had the understanding and

the courage to commit to writing an explanation of the phases of the moon, was but a recent authority and his book little esteemed. In fact, it circulated in secret, was read by few, and was cautiously received. For in those days there was no tolerance for the natural philosophers or "babblers about things in heaven" as they were called. They were charged with explaining away the divine and substituting for it irrational causes, blind forces, and the sway of necessity. So Protagoras was banished, Anaxagoras was gaoled and it was all that Pericles could do to get him out, and Socrates, though he had nothing to do at all in the matter, was put to death for being a philosopher. *It was only much later, through the brilliant repute of Plato, that the reproach was removed from astronomical studies and access to them opened up for all. This was on account of the respect in which his life was held and because he made natural laws subordinate to the authority of divine principles.*'

Such is Plutarch's account of the matter. Nor are we dependent only on such a late authority. In a curious passage in the *Laws* (820–822) Plato himself gives us the same information. There he makes his mouthpiece say that a new astronomical discovery has made it unnecessary to submit to the generally accepted view that astronomy is a dangerous and impious study. And what is this new discovery? Simply that the sun, moon, and with them those vagabonds, the planets, do not really move irregularly, as they appear to do. Accordingly, says Plato, our attitude to the teaching of astronomy needs to be revised. It has now become a safe, even a desirable subject, up to a point. Students must by no means be allowed to hear, as the old natural philosophers taught, that the sun and moon are lumps of inanimate matter. But they will pray and sacrifice to the heavenly bodies in a more acceptable spirit when they have been made to understand that they are

divine beings whose motions are patterns of regularity.

This kind of astronomy, in which natural laws were subordinated to divine principles, and in which more regard was paid to the heavenly bodies as objects of worship than subjects of scientific study, was further developed by Aristotle. Systematizing the doctrines of Plato and the Pythagoreans, he taught, not only that the circular motions of the heavenly bodies are proof of their being under the control of divine intelligence, but that the very substance of which they are made – what he called 'the fifth element', to distinguish it from Earth, Air, Fire, and Water – is different from any that exists below the circle of the moon. The astronomy which he taught in his theological mood (it must be stressed that it is not characteristic of his scientific outlook) is that inherited by the Middle Ages.

Aristotle's account was that the universe consists of fifty-nine concentric spheres, with the earth at the centre. To the earth were allowed four spheres, one for each of the four elements. Outside the four terrestrial spheres were fifty-five celestial spheres, that of the moon being the lowest and that of the fixed stars the highest. The spheres were supposed to revolve round a stationary earth and carry with them, in their revolutions, the heavenly bodies. Only below the moon, in Aristotle's scheme of the universe, was change possible. There the four elements, whose 'natural' movements were up and down, might mingle and be transformed into one another. But above the moon, in the etherial spheres, whose 'natural' movement was in circles, no change occurred. In this scheme, as the substance of heaven is different from that of earth, so are the laws of motion different. There is a celestial mechanics and a terrestrial mechanics, and the rules of one are not valid for the other. Not till Newton did terrestrial mechanics regain control of heaven.

It would be wrong, however, to leave the impression that the Platonic compromise, which sought to 'make natural laws subordinate to divine principles', met with no opposition or was universally accepted. Aristotle himself affords proof of the uneasiness with which it was regarded. In the account of his astronomical opinions which we have given so far we have been following his treatise *On the Heavens*, which seems to be an early work written when he was strongly under the influence of Plato and the Academy. In his *Metaphysics* (XI. 8, 1073b 8 ff.), discussing the apparent motion of the heavenly bodies, he puts forward a more cautious view which is worth quoting. 'That the movements are more numerous than the bodies that are moved is evident to those who have given even moderate attention to the matter; for each of the planets has more than one movement. But as to the actual number of the movements, we now - to give some notion of the subject – quote what some of the mathematicians say, that our thought may have some definite number to grasp; *but, for the rest, we must partly investigate for ourselves, partly learn from other investigators, and if those who study this subject form an opinion contrary to what we have now stated, we must esteem both parties, indeed, but follow the more accurate.*'

This is spoken like the great scientist that Aristotle was; and it is relevant here to observe that sometimes, even when Aristotle reverses a *correct* opinion of his predecessors, he does so because he is in possession of more abundant evidence than they. Some justification may be found, from this point of view, even for his disastrous separation between terrestrial and celestial mechanics. The old Ionians, ignorant of the true or even approximate sizes of the heavenly bodies, their distances from one another, and their distances from earth, had been incapable of a true distinction between astronomy and meteorology. For them the heavenly bodies were small

in comparison with the earth. A couple of centuries of the application of mathematics to astronomy had changed all this. Aristotle can casually remark (*Meteorologica*, 340a), 'The bulk of the earth is infinitesimal in comparison with the whole universe which surrounds it'. Accordingly, while the Ionians could argue, without misgiving, from processes going on on earth to processes in the sky, Aristotle felt he could no longer do so. 'It is absurd,' he writes, 'to make the universe to be in process of change because of small and trifling changes on earth, when the bulk and size of the earth are surely as nothing in comparison with the whole universe' (*Ib.*, 352a). Aristotle could thus support his incorrect celestial philosophy by the latest findings of astronomy. Science does not advance evenly along its whole course, but, like the planets, now hurries, now halts, and sometimes even seems to be in reverse.

The second gain we put to the credit of thinkers before Plato was the progress made towards the conception of positive science and the beginnings of a correct theory of the rôle of observation and experiment in the building up of the positive sciences. What was Plato's attitude to the new habit of interrogating nature in order to wrest her secrets from her? On the whole, it must be admitted that he was opposed to it. It is in regard to astronomy and acoustics that he expresses his attitude most clearly. We shall take up these two subjects in turn.

In his dialogue the *Phaedo*, in which he expounds the doctrine of the immortality of the soul, Plato makes Socrates say: 'If we are ever to know anything absolutely, we must be free from the body and behold the actual realities with the eye of the soul alone. ... While we live we shall be nearest to knowledge when we avoid, so far as possible, intercourse and communion with the body, except what is absolutely

necessary, and are not infected by its nature, but keep ourselves free from it until God himself sets us free.' There is no room for doubt that Plato allowed this desire, to be free from the body and behold the actual realities with the eye of the soul alone, to affect his attitude to research. It checked the impulse to physical research and shifted the whole emphasis to abstract mathematics. Plato was one of those who was prepared to listen to Parmenides. Like him, he distrusted the blind eye and the echoing ear.

In *Republic* vii, 529, 530 he gives the following advice with regard to astronomy: 'The starry heaven which we behold is wrought upon a visible ground, and therefore, although the fairest and most perfect of visible things, must necessarily be deemed inferior far to the true motions of absolute swiftness and absolute slowness. ... These are to be apprehended by reason and intelligence, but not by sight. ... The spangled heavens should be used as a pattern and with a view to that higher knowledge. ... But a true astronomer will never imagine that the proportions of night and day, or of both to the month, or of the month to the year, or of the stars to these and to one another, and any other things that are material and visible can also be eternal and subject to no deviation – that would be absurd; and it is equally absurd to take so much pains in establishing their exact truth. ... In astronomy, as in geometry, we should employ problems, and let the heavens alone if we would approach the subject in the right way.'

His attitude to experiment in acoustics is as hostile as his attitude to observation in astronomy. In a continuation of the passage on astronomy just quoted, he makes Socrates complain: 'The teachers of harmony compare the sounds and consonances which are *heard* only, and their labour, like that of the astronomers, is in vain.' To which Glaucon rejoins:

'Yes, by heaven! And it is as good as a play to hear them talking about their condensed notes, as they call them; they put their ears close alongside of the strings like persons catching a sound from their neighbour's wall – one set of them declaring that they distinguish an intermediate note and have found the least interval which should be the unit of measurement; the others insisting that the two sounds have passed into the same – either party *setting their ears before their understanding*.' Socrates fully approves of this: 'You mean those gentlemen who tease and torture the strings and rack them on the pegs of the instrument ... they too are in error, like the astronomers; they investigate the numbers of the harmonies which are *heard*, but they never attain to problems.' From all of which two things are apparent: first, that a certain amount of systematic experiment was going forward, and second, that Plato strongly discouraged it.

Here again, as in the matter of reviving the belief in the divinity of the stars, Plato marks a reaction. But again, as before, there is something to be said on the other side. Plato added nothing to science in the observational and experimental sense. It is extremely doubtful whether he added anything to mathematics. Heath's judgment on his mathematical attainment is that 'he does not appear to have been more than up to date' (*op. cit.*, p. 294). But he did contribute to the philosophy of mathematics. What fascinated him was the meaning of those mathematical truths which seem to be independent of experience. In *Republic* vi, 510, he says of the geometers: 'You know that they make use of visible figures and argue about them, but in doing so they are not thinking of these figures but of the things which they represent; thus it is the absolute square and the absolute diameter which is the object of their argument, not the diameter which they draw.' In distinguishing this type of knowledge from the

knowledge which appears to be wholly dependent on sensuous impressions, Plato made a fundamental contribution to epistemology. It is his concern for this that must excuse, if anything can excuse, a hostility to practical geometry so great that he regarded the mere construction of figures as essentially antagonistic to a true study of the subject.

When we come to the third point, the connection between philosophy and the techniques, which had proved so fruitful in an earlier period, we find that Plato has nothing to contribute. Preoccupied with theological, metaphysical, or political problems, and disbelieving in the possibility of a science of nature, Plato has little appreciation of the connections between Greek thought and Greek practice which were clear to an earlier age. These connections are many. Astronomy was, of course, not studied out of mere curiosity. It was studied in order to solve those very problems concern with which Plato deprecates – the exact relations of the lengths of day and night, of both to the month, and of the month to the year. On the solution of these problems depended the improvement of the calendar. On the improvement of the calendar depended improvements in agriculture, navigation, and the general conduct of public affairs. Neither was geometry studied, outside the Academy, purely for the good of the soul. It was studied in connection with land-surveying, navigation, architecture, and engineering. Mechanical science was applied in the theatre, the field of battle, the docks and dockyards, the quarries, and wherever building was afoot. Medicine was a conspicuous example of applied science. It was a scientific study of man in his environment with a view to promoting his well-being. But the political programme put forward by Plato in the *Republic* and the *Laws* is all but barren of understanding of the rôle of applied science in the improvement of the lot of humanity. In his *Republic* and

Laws Plato is wholly occupied with the problem of managing men, not at all with the problem of the control of the material environment. Accordingly the works, if full of political ingenuity, are devoid of natural science.

Plato carries this hostility, or indifference, to the science implicit in the techniques to very great lengths. A characteristic of the Ionian scientists had been the honour paid to great inventors, such as Anacharsis, who invented the bellows and made an improvement in the design of the anchor, or Glaucus of Chios, who invented the soldering-iron. These were examples of human ingenuity to an older age. Plato, however (*Republic* x, 597), did not think a human craftsman could originate anything; he had to wait for God to invent the Idea or Form of it. A carpenter, says Plato, could only make a bed by fixing his mind's eye on the Idea of the bed made by God. Theodorus of Samos, who invented the level, the lathe, the set-square, and the key, was thus shorn of his originality and of his title to honour; and Zopyrus, who invented the *gastrophetes*, or cross-bow held against the belly, had stolen the patent from God. The propounders of the modern theory of evolution found themselves embarrassed by the teaching of the Old Testament, that the various species of plants and animals, as they now exist, had been created by God. The technicians of the ancient world must have found it still more embarrassing to be told to wait upon the divine initiative before originating, or even improving, any technical device, since the present stage of technical development represented the divine plan.

But Plato went farther than this in depressing the intellectual status of the technician. Not only is the technician robbed of the credit of inventiveness, he is also denied the possession of any true science in the art of manufacture. By an ingenious piece of sophistry Plato proves, in the same

passage of the *Republic*, that it is not the man who *makes* a thing, but the man who *uses* it, who has true scientific knowledge about it. The user, who alone has true science, must impart his science to the maker, who then has 'correct opinion'. This doctrine effectually exalts the position of the consumer in society and reduces the status of the producer. Its political importance, in a slave-owning society, is obvious. A slave who made things could not be allowed to be the possessor of a science superior to that of the master who used them. But it constitutes an effective bar to technical advance or a true history of science. Plato has here, in fact, prepared the way for the grotesquely unhistorical opinion later current in antiquity, that it was philosophers who invented the techniques and handed them over to slaves.

Why did Plato think in this way? Plato had one of the best brains of which human history holds record. Why do his arguments lead sometimes to such wrong-headed conclusions? The answer is not difficult to give. It will be argued more closely in our last chapter. Suffice it here to suggest that Plato's thought was corrupted by his approval of the slave society in which he lived. Plato and Aristotle regretted the fact that any free labour still survived. In his *Politics* (Bk. I, chap. xiii) Aristotle remarks: 'The slave and his master have a common existence; whereas the artisan stands to his master in a relation far less close and participates in virtue only in so far as he participates in slavery.' In his *Laws* Plato organizes society on the basis of slavery, and, having done so, puts a momentous question: 'We have now made excellent arrangements to free our citizens from the necessity of manual work; the business of the arts and crafts has been passed on to others; agriculture has been handed over to slaves on condition of their granting us a sufficient return to live in a fit and seemly fashion; how now shall we organise our lives?' A still

more pertinent question would have been: 'How will our new way of life reorganise our thoughts?' For the new way of life did bring a new way of thinking, and one that proved inimical to science. It was henceforth difficult to hold to the view that true knowledge could be arrived at by interrogating nature, for all the implements and processes by which nature is made to obey man's will had become, if not in fact yet in the political philosophy of Plato and Aristotle, the province of the slave.

We have now examined the respects in which Platonism constitutes a reaction from Ionian science. Plato, however, had an all-important contribution to offer in another sphere. The debate as to whether the reason or the senses are the true path to knowledge was now an old one. Plato had come down strongly on the side of reason. The consensus of opinion among scientists was that reason could not contribute anything without the evidence of the senses. Plato could not avoid the discussion, and in two dialogues, the *Theaetetus* and the *Sophist*, his treatment of it yields results of classic importance.

In the former dialogue, abandoning the intransigent attitude of the *Phaedo*, Plato is prepared to admit that the data of sensation are the material of knowledge, but insists (as, indeed, others had done before him) that sensation is not in itself knowledge. Here he makes a more thorough analysis of the problem than his predecessors, the Hippocratic doctors, whose opinions we have quoted, had done. He clearly distinguishes between sense-perception and thought, and teaches that knowledge is the result of the action of the latter on the former. We may quote his own words. 'The simple sensations which reach the soul through the body are given at birth to men and animals by nature, but their reflections

on these and on their relations to being and use are slowly and hardly gained, if they are ever gained, by education and long experience.'

Here there is a very valuable thought very clearly expressed. But even here it might be urged that, if Plato had been able to follow out the train of his thought to its logical conclusion, the result would have disrupted his whole philosophy as dramatically as the discovery of the irrationality of $\sqrt{2}$ did the number physics of the Pythagoreans. For it is obvious that, if the source and growth of knowledge are such as Plato now describes – namely, reflection on simple sensations matured by education and experience – then human consciousness is externally conditioned by nature and by society, and does not consist in the perception by the soul of eternal verities. If Plato had pursued this line of thought, he would have had to admit, with the Ionians, what in the back of his mind he clearly knew, the connection between human practice and human knowledge. In short, he would have been dangerously near to adopting the views of Democritus. But it is time to stop speculating on what Plato might have said and report what he actually did say.

As we have seen, Plato had now arrived at the position that the sensory faculties are organs by which *mind* apprehends external nature. We proceed to give, in condensed form, the further steps of his argument – 'We do not see with the eyes but through them. We do not hear with the ears but through them. Nor could any one sense itself distinguish between its own activity and that of another sense.' A new point this, and a fine one, of which there was no hint in the Hippocratic writers. 'There must be something connected with both senses,' Plato continues, 'call it soul or anything else you like – *with* which we truly perceive all that is conveyed to

us *through* the sensory faculties. It is the soul, or *psyche*, that makes us aware that we perceive and that distinguishes the data of one sense-organ from those of another.'

The contribution here made is already of first importance, and Plato has still more to give. He points out that we have other psychic activities less directly dependent on sense-stimulation than those already mentioned. Such activities are recollection, expectation, imagination, and those higher operations of the mind by which we apprehend mathematical or logical arguments, or lay hold of such absolute Ideas as the Good, the Beautiful, and the True. It is not necessary to accept Plato's view that these activities prove the immortality of the soul and its independence of the body, in order to admit that he has here raised the whole problem of consciousness to a higher level.

In the *Sophist* the immateriality of the soul is strongly emphasized. The materialists are impaled on the horns of a dilemma. Do they, or do they not, admit the existence of soul, and that some souls are wise and good, others foolish and bad? If they say Yes, as they must, they are to be asked whether this does not imply that wisdom and the other virtues are something, and whether they are things that can be seen and handled. They may try to save themselves by saying that the soul is a kind of body. They will find it hard to say that wisdom is a kind of body. If they can be got to admit that anything can *be* without being a body, the point has been gained.

We cannot pursue further this early stage of the now ancient controversy on the nature of the soul. But it is fair to add that we know what answer the materialists made. The Epicureans have preserved it for us. They said: Yes, we admit, of course, the existence of soul, of mind, of characters good and bad; we merely deny their existence apart from the

appropriate physical and physiological structure, 'far away from the sinews and the blood'.

We conclude that Plato not only made no direct contribution to positive science, but did much to discourage it. That is not to say, however, that he made no contribution to thought. He fostered the study of mathematics, an essential element in the modern conception of science. He advanced the study of logic more than all the thinkers who preceded him. His criticism of the rôle of sense-perception and mind in the process of the cognition of the external was epoch-making. The foundation of the Academy was no mean contribution to the conception of science as an organized and co-operative effort. The composition of his great series of dialogues, touching so many aspects of human life and thought with language of subtlety and power, was an imperishable gift to mankind. As for what was corrupt in his thought, we shall best understand it and most fairly judge it when we see in it the corruption of the age. For the most vital, the most valuable, thing in Plato is that he endeavoured to think like a citizen, even if a reactionary citizen of a decaying society. It is his sense of the social and political implications of men's thought on every subject under heaven that both warps his own thinking and lends it life, complexity, passion, weight. When we observe him, who had such a luminous intellect, putting the lamps of knowledge out, we see through his personal crisis into the crisis of ancient society. He lacked the serenity of a former age when to think meant to foresee progress for mankind. When he looked into the future he was afraid. But he was not above the battle. He was the least in the world like the pure philosopher lost to all considerations of place and time that his present defenders represent him to be.

CHAPTER EIGHT

Aristotle

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WE HAVE spoken of Plato as being the first philosopher whose writings have survived in bulk. Aristotle was both a great philosopher and a great scientist, and his writings have also survived in bulk. Apart from the Hippocratic writings, which are with difficulty ascribed to definite authors and represent a school rather than a man, the Aristotelian corpus is the first body of scientific writings to survive. He is the earliest Greek scientist whose works can be adequately studied in their original form. From Thales to Democritus we are dependent on fragments, on later quotations and comments. We have voluminous treatises from the pen of Aristotle.

But though the works of both Plato and Aristotle have survived, the fortune of the two men has been very different. We have all the works of Plato which he prepared for publication, we merely guess at the substance of his lectures in the Academy. Aristotle, when he was still a member of the Academy, wrote and published dialogues. We have lost them all. What we do possess is the substance of the lectures he gave as head of his own institution, the Lyceum. The works of Aristotle which we possess are technical treatises. With the exception, therefore, of isolated passages of general import and exceptionally finished form, Aristotle is not readable as Plato is.

Neglecting certain smaller works we may classify the Aristotelian writings under four heads – (1) physical, (2) logical and metaphysical, (3) ethical and political, (4) bio-

logical. *The physical treatises*, from the point of view of modern science, are the least satisfactory. They are under the domination of the teleological philosophy of the Academy. *The logical and metaphysical treatises* represent a great effort of criticism of the work of his predecessors, especially of Plato. The net result of Aristotle's criticism is to transform the Ideal Theory into an instrument for the study of nature. With Aristotle the Ideas or Forms do not exist apart from nature, but are embodied in nature and have no other existence. Science consists in finding the permanent Forms which underlie the shifting phenomena of nature. With *the ethical and political treatises* we cannot be directly concerned here; but they are of great importance, nevertheless, in so far as they reveal to us the connections, which are numerous and intimate, between Aristotle's views on nature and his views on society. In *biology* Aristotle made his great contribution to science. It has been called the greatest contribution to science ever made by an individual.

Obviously the mental history of such a man as Aristotle, if we could come by it, would be of extraordinary interest. We may feel confident that we do, in its main outlines, possess that history, though it has been understood only quite recently. It *is* of extraordinary interest. But how can we be sure that we possess it? And how did it lie concealed so long?

It must be understood that the interest in the mental history of the individual is quite a modern thing. Plato has given us a voluminous account of the life and conversation of Socrates. In vain do we look in it for an intelligible account of the mental development of his hero. Socrates was the wisest man Plato knew, Plato makes him the vehicle for his own wisdom. He did not play Boswell to Socrates' Johnson. Plutarch, again, has left us a gallery of portraits of the great men of Greece and Rome. He accepted no sitter unless he

was a general or a statesman. No artist, scientist, or philosopher figures in the list. It is not biography in the modern sense that Plutarch writes, but rather military and political history from a new angle, that of the individual participants. The same is true of his Roman imitator, Cornelius Nepos. The great crisis of the ancient world, the breakdown of paganism and the evolution of Christianity, inaugurated a change. In the *Meditations* of Marcus Aurelius and the *Confessions* of St. Augustine, we have the records of mental histories, but they bore no great fruit. When the Christian world had taken shape we begin to get again an abundant biographical literature. But the Lives of the Saints are not, except in the most superficial sense, the mental histories of men. They are schematized accounts of the operations of Divine Grace. It was the movement of Humanism that foreshadowed the birth of biography in the modern sense.

But long before this, Aristotle, an Aristotle without mental development, had become part of European culture. The mediæval schoolmen constructed Christian theology on the basis of Aristotle's works. Scientists at the Renaissance accepted or rejected Aristotle's views. In either case 'Aristotle' meant anything that had survived with Aristotle's name attached to it. All his writings had equal authority. No one knew in what order his works had been written, or bothered to enquire. That is the reason why the mental history of Aristotle was concealed from us.

The detailed reconstruction of the order of composition of Aristotle's works is not easy. Probably it is impossible. To his pupils at the Lyceum, Aristotle lectured on a vast range of subjects over a period of many years. His courses on all these subjects grew under his hands. They have in them earlier and later strata, and have numerous cross-references

to one another. Nevertheless their general development is clear. The acceptance by W. D. Ross (*Aristotle*, p. 19) of the order of composition suggested by Werner Jaeger in his *Aristoteles* represents the final judgment of informed opinion. With this order the mental development of Aristotle corresponds to the external events of his life.

Aristotle was the son of a physician at the court of the Macedonian king Philip II, and doubtless was expected to follow his father's profession. It is almost certain that, in accordance with the practice of the time, he had been apprenticed to his father's art. If so, he had, as a boy, had opportunity to understand the double aspect of Hippocratic medicine, which was, as we have seen, both a science and a technique. He would have conceived of the healing art as a growing body of positive knowledge; and, as a future practitioner in that art, he would have been taught to let blood, to bind wounds, to apply poultices, and perform many other simple medical operations. Then, as a youth of about seventeen, we find that he had transferred himself to the Academy at Athens, there to be introduced to a different mental and spiritual world. He would now receive an initiation in Pythagorean mathematics which would be succeeded by a rigorous training in dialectics. He would be taught to understand things, as Parmenides had advised, not through the senses but through reasoning. He would accept the Parmenidean maxim that the logical and the real are identical. The goal of his ambition would no longer be to know nature but the absolute. He would meditate long on the words of Socrates in the *Phaedo*: 'If we are ever to know anything absolutely, we must be free from the body and must behold the actual realities with the eye of the soul alone.'

Together with this introduction to the ideal philosophy, Aristotle would learn in the Academy to despise techniques.

If as a boy he had learned to employ the hand in healing, he would now be taught that to employ the hand in learning, even to the limited extent of making physical models of mathematical objects, was a vulgar thing of which he ought to be ashamed. But probably Aristotle did not need this lesson. His early training in surgery would not imply exemption from the growing prejudice against manual labour in general. The important thing for his future career as a biologist was that in this one department at least he was not ashamed to use his hands.

Aristotle remained nearly twenty years in the Academy. Jaeger has remarked that so protracted a pupilage in a man afterwards distinguished for originality is without parallel in the intellectual history of mankind. It must, however, be remembered that Aristotle was already an author of repute while still a member of the Academy. 'The ancient schools of philosophy,' Ross reminds us, 'were bodies of men united by a common spirit and sharing the same fundamental views, but following out their own enquiries in comparative independence.' That Aristotle was, while still a member of the Academy, critical of some features of Platonism is clear, and in 348, when Plato died and was succeeded in the headship of the Academy by his nephew Speusippus, the divergence of view became still more marked. Aristotle complained of the tendency of the Academy to 'turn philosophy into mathematics' and abandoned it. He would be then about thirty-five years old.

The next thirteen years of his life were spent away from Athens, mainly in Assos and Mitylene. To this period belong many of his researches in biology. Fleeing from Athens and mathematics, Aristotle took refuge in Ionia and natural history. Would that we knew more of his associates at this time and of the strength of the old Ionian tradition! Then,

in 334, being now near fifty years of age, Aristotle returned to Athens and set up school for himself at the Lyceum. To the next twelve years, when he was head of the Lyceum, the completion of his own wonderful extant corpus of writings belongs. He withdrew again from Athens in 323, and died the next year. The inner tension in his writings, producing glimpses of a spiritual drama underneath their dry technical exterior, resides in his combination of respect for Platonic idealism with devotion to positive research. 'If we ask in what order it is psychologically most likely that Aristotle's works were written,' says Ross, 'the answer must be that presumably his writings would reflect a progressive withdrawal from Plato's influence. ... The general movement was from otherworldiness towards an intense interest in the concrete facts both of nature and of history, and a conviction that the "form" and meaning of the world is to be found not apart from but embedded in its "matter".'

A hundred and forty years ago the famous Platonist, Thomas Taylor, summed up the general difference between the two philosophers by remarking that Aristotle, even when he considered theology, did so physically, while Plato considered even physics theologically. The theological physics of Plato are set forth in his famous, or notorious, dialogue, the *Timaeus*, and the best introduction to the physical treatises of Aristotle, which are the earliest and most Platonic part of his extant writings, is the *Timaeus*. In this dialogue Plato gives an account of the creation of the world. The work constitutes the high point of the Pythagorean tradition of theological philosophy. Its teaching is that the phenomenal world is an image of the eternal world, and that the cause of the creation of this phenomenal world on the model of the eternal world is the goodness of God. In other words, its major themes are providence and teleology. *A priori* argu-

ments are adduced for the opinion that the world is one, that it is in the form of a perfect sphere, that it is necessarily made up of the four elements, Earth, Air, Fire, and Water, and that it has a soul. Human bodies, we next learn, are likewise made up of the four elements and likewise contain souls. These souls have been divinely instructed in the moral law of the universe. The purpose of God in endowing men with sight and hearing was that they might learn the lesson of law and order from astronomy and music and apply it to their own lives.

The following passage, which seeks to explain why the world had to be made of the four elements, will make clear what Thomas Taylor meant when he said that Plato treated physics theologically. 'Being bodily, that which has come to be must be visible and tangible. Without fire nothing visible can come to be, nothing tangible without solidity, nothing solid without earth. Hence God, in the beginning of his fashioning, made the body of the universe out of fire and earth. Now two terms cannot be brought together without a third. There must be a bond between them to bring them together. ... If the body of the universe could have been a plane without depth, one middle term would have sufficed to bind together the extremes and itself. But in fact the world was to be solid, and solids must always be conjoined not by one middle term, but by two. So God inserted water and air between fire and earth, and made them all, so far as was possible, proportional to one another, air being to water as fire to air, and water to earth as air to water.' The magic wand of Pythagorean mathematics has transformed the natural philosophy of the Ionians into theology.

The constitution of human bodies is treated in the same *à priori* way by verbal logic. The pathology of both body and mind is deduced from the general account of the structure of

the universe, in the manner long before denounced by the author of *Ancient Medicine*. By way of *finale*, the existence of women and the other lower animals is accounted for by a doctrine of the progressive deterioration of men! 'Those of the men first created who led a life of cowardice and injustice were suitably reborn as women in the second generation, and this is why it was at this particular juncture that the gods contrived the lust of copulation.' 'Beasts who go on all fours came from men who were wholly unconversant with philosophy and had never gazed on the heavens.' When he goes as far as this Plato is probably intending to be consciously funny, but it is to be noted that his shafts of wit are directed against the old Ionian thinkers. Anaximander, anticipating modern views and basing himself on evidence, had taught that man was descended from a fish. Accordingly Plato maintains that fish are descended from men. 'The fourth kind of animal, whose habitat is water, came from the most utterly mindless men.' And if, says Plato, fools like Anaximander have been turned into fish, other philosophic fools have been turned into birds. 'Birds sprang by a change of form from harmless but light-witted men who paid attention to the things in the heavens but *in their simplicity supposed that the surest evidence in these matters is that of the eye*'.

But it is not merely, or even principally, the use of the senses that Plato protests against in the *Timaeus*. In quarrelling with the philosophy of the old Ionians he is also concerned to dismiss the modes of explanation of natural phenomena which, as we have seen, they had drawn from techniques, and to substitute for them modes of explanation drawn from Pythagorean mathematics and Parmenidean logic. The kind of concepts Plato will not admit are solidification, liquefaction, inflammation, coalescence, condensation and so forth, that is to say, physical processes which men

control in techniques. What he substituted for them can be seen in the following typical passage.

'When the ordering of the universe was set about, God first began by laying out by figure and number the patterns of fire and water and earth and air, which heretofore, though shewing some vestiges of their structure, were altogether in such a state as might be expected when God is absent. *That He shaped them to be, as they had not been before, wholly beauteous and good, so far as might be, we must assume throughout as our standing principle.* What I have now to disclose to you is the particular structure and origin of them each and all. The argument will be novel, but you have been schooled in the branches of knowledge needed for the explanation of my propositions and so will be able to follow. First, then, it must be obvious to anyone that fire, earth, water and air are bodies, and all body has volume. Volume, again, is necessarily enclosed by surface, and rectilinear surface is composed of triangles. All triangles are derived from two, and each of these has one right angle and two acute. One of them has, on either side, half a right angle, subtended by equal sides. The other has, on either side, unequal parts of a right angle subtended by unequal sides. *So we postulate this as the source of fire and of the other bodies, as we pursue our argument which combines necessity with probability.* What still more recondite sources there may be of these bodies is known to God and such men as God loves.' Thus the nature of fire is explained by the properties of the scalene triangle. The argument is famous in history. Nevertheless its importance would seem to be less than that of the elder Pliny's description of the rôle of fire in techniques.

'The safest general characterisation of the European philosophical tradition,' says Whitehead, 'is that it consists of a series of footnotes to Plato.' As we are not here concerned,

except incidentally, with philosophy, it is not our intention to discuss this dictum. We merely wish to enter a caution against the mistake of regarding Plato as being equally important for the history of science. From the scientific point of view the *Timaeus* is an aberration.

Aristotle, who was born about the time the *Republic* was composed, was a student at the Academy in his twenties when the *Timaeus* was being written. The *Timaeus* gives us the mode of explanation of the universe in which he was systematically trained. We have already seen in our last chapter how Aristotle contributed to the elaboration of Plato's theological astronomy. The whole of his physics is also inspired, and vitiated, by the Platonic ideal. It is not contended that in these writings acute argument will not be found. Chapter 8, Book II of the *Physics*, in which nature is proved to be teleological, may be recommended to the attention of the reader. If not convincing, it is at least interesting. Nor is criticism of his predecessors absent. Even Parmenides and Plato come in for their share of it. Still it is their spirit that presides over the work. It is what Bacon called disputatious. The modern reader cries out for evidence, not argument.

> Nur das Beispiel führt zum Licht;
> Vieles Reden thut es nicht.

It is the same with the other physical treatises. Plato had assumed throughout as his standing principle that God had shaped things to be, so far as might be, wholly beauteous and good. With the substitution of Nature for God, it is precisely the same teleology that informs, for instance, Aristotle's treatise *On the Heavens*. The heaven is a sphere, *because* a sphere is the perfect figure; it rotates in a circle, *because* only circular motion, having no beginning and no end, is eternal,

and so on. *On the Heavens* is an exercise in the manner of the *Timaeus*.

But, as we have already seen, Aristotle became gradually more and more convinced of the necessity of observation, and of the primacy of clear sense-evidence over any argument, however plausible. 'I decided to take refuge from the confusion of the senses in argument and by means of argument to determine the truth of reality,' Socrates is made to say in the *Phaedo*. Not without hesitation Aristotle reversed this course and decided to give sense-evidence the primacy where it promised greater accuracy. Accordingly, the element of observation shows a steady tendency to increase in his physical treatises. The *Meteorologica* comes late among the physical writings, as is clear from the fact that Book I begins with a *résumé* of what is in the earlier works – the *Physics*, the treatise *On the Heavens*, and that *On Generation and Corruption*. Ross, while observing that the information, even in this late treatise, is 'rendered to a large extent nugatory by *à priori* theorising', rightly stresses the fact that 'throughout there is evidence of a very considerable amount of close observation'.

We quote some of his remarks on the moon rainbow in support of this contention. 'The rainbow is seen by day, and it was formerly thought that it never appeared by night as a moon rainbow. This opinion was due to the rarity of the occurrence: it was not observed, for, though it does happen, it does so rarely. The reason is that the colours are not easy to see in the dark and that many other conditions must coincide, and all that in a single day in the month. For if there is to be a moon rainbow it must be at full moon, and then as the moon is either rising or setting. So we have met with only two instances of a moon rainbow in more than fifty years.'

As we have already indicated, the problem of the rival

claims of sense and reason had occupied the attention of Plato throughout his life, and in his dialogues, *Theaetetus* and *Sophistes*, he had made a notable contribution to its solution. The problem continued to trouble Aristotle throughout the whole of his work on physical topics. It was, in fact, the driving-force of his developing thought; and in the next great division of his writings, his metaphysical and logical treatises, we find his answer to it.

It is perhaps natural that those mainly interested in the growth of positive scientific knowledge should regard this problem with some impatience. The impatience is unjustified, for the emergence of the idea of positive science necessarily brings with it the problem of the validity of knowledge. As soon as men consciously consider the problem of Being, of existence, they inevitably raise for themselves the new problem of Knowing, of consciousness. What is apprehended by thought is not an immediate datum of sensation. If we call a hundred objects present to our sight by the one name of star, we do so in virtue of something they share in common, though they are all different. As soon as we try to define what they have in common, we have begun to philosophize. If we say, with Thales, that everything that exists is Water, we are plunging still deeper into metaphysics. Stars differ in position, but they are more or less the same sort of thing. But what have Water, Earth, Fire, and Air in common, that we should seek to establish an identity in such manifest difference? In pursuit of such problems, the mind soon creates for itself a whole apparatus of concepts by means of which it seeks to understand nature. The problem of Being has called into existence the problem of Knowing.

The Ideal Theory, which we associate with the name of the Platonic Socrates, was an attempt to solve the problem of knowing. Knowing things means bringing things under

classes. To classify things you must define what is essential to them, what is their Idea or Form. This Idea or Form is the permanent and intelligible aspect of things. Everything, as Heraclitus taught, is in a state of flux. But what flows, what changes, is the sensible element in things. The intelligible aspect, the Idea, remains. The Idea alone has validity for thought. Plato accorded the Idea a separate existence of its own – he hypostatized the Idea, as the technical expression goes – and taught that the only valid science was knowledge of the Ideas. Of the changing world of sense we could never hope, he taught, to have more than 'correct opinion'. This Ideal theory had its *religious* aspect. It was knit up with the belief in the immortality of the soul. The immortal soul, before incorporation in a man's body at birth, had knowledge of the eternal patterns or archetypes of things. The body, with its obscure sensations, gave knowledge only of the flux of the phenomenal world. The Ideal Theory, as the writer of this book contends, had also its *social* aspect. It was a leisure-class theory. It was a theory only possible to men who only thought about things and did not act upon them. The Idea became separated from the thing, when the thinker became separated from the doer. Bacon saw the point and put it clearly. He called the Forms of things 'the laws of simple action', and sought for such a science as would enable men to act upon matter.

Now, the desire to *act* upon matter never troubled Aristotle any more than it troubled Plato. His physical treatises are as devoid of concepts derived from techniques as the *Timaeus* itself. From the practical point of view the Ideal theory held no inconvenience for them. The difficulty about the Ideal theory, which to some extent bothered Plato and which gave Aristotle no rest, was that it implied the abandonment of the attempt to establish a science of nature, and

itself constituted an insuperable obstacle to it. The eye of the soul might suffice to inform one about the world of Forms. Only the eye of the body could bring the necessary data for a science of nature. The result of Plato's later thought about this problem was a tacit abandonment of the Ideal Theory and the substitution for it of a distinction between matter and mind. Plato had a picture of a material universe that was either motionless or disorderly. Over against this he set Mind, which was the source of life and orderly motion, and which brought harmony, proportion, and intelligibility into matter. To the division of the universe into matter and mind corresponded the division of man into body and soul.

This whole enquiry Aristotle took up again in his *Metaphysics*. The book is an enquiry into the nature of reality, and, as Aristotle was executing a 'progressive withdrawal' from Plato's influence', the main problem to be considered is whether the Platonic Forms exist and, if so, in what sense. His answer, to put it briefly, is that the Forms do exist, but always in inseparable association with matter. The hypostatization of the Ideas is openly and decisively set aside. Matter and Form appear as two aspects of existence.

This is a great advance on the Ideal Theory. The problem is brought farther towards a solution by being merged in a larger question, the general question of cause. Aristotle differs from Plato in making more allusion to his Ionian predecessors, not avoiding even the dreaded name of Democritus. He seeks to put the doctrine of the Academy, and his own development of that doctrine, in its historical setting. Out of the whole movement of thought on the nature of things from Thales to himself he sees developing a fourfold theory of cause. The early Ionians, with their quest for a First Principle, had been looking for the *material* cause of things. The Pythagoreans, with their emphasis on number,

had hinted at the *formal* cause. Heraclitus, with the active rôle he assigns to Fire, Empedocles, with his doctrine of Love and Hate, had been concerned to find the *efficient* cause. Socrates, in insisting that the reason for things being *so* rather than *so* is because it is best that they should be as they are, had suggested the *final* cause. An adequate explanation of nature must recognize the fourfold nature of cause.

This new doctrine of cause hardly did justice to the rich experiential content of the teachings of the older philosophers, but it cleared the ground for a fresh advance in another field. Aristotle created almost *ab initio* a new science, or technique, that of logic. The object of this science was to determine the limits of validity of the exercise of reason in arriving at a knowledge of reality and in communicating it. So long as the Platonic doctrine of Ideas held the field it was not possible that the science of logic should develop. For Plato could not bridge the gap between the Ideas, which were the only objects of true science, and the phenomenal world, which lay beyond the reach of science. Plato's Logic could not give knowledge of the natural world. But Aristotle had advanced to the view that the Idea had no separate existence, that what really exists is the concrete individual thing, a union of matter and form. The only realitv is 'immattered form'. Form, since it has no separate existence, cannot be apprehended except by the study of the thing. To arrive at the universal we must study the particulars. But this is the very problem of logic. What are the valid processes by which we arrive at the universal by the study of the particulars? How can we find the Form in Matter? And having found it, how can we validly discuss it, utilize it, and draw conclusions from it? The Aristotelian doctrines of Induction, Definition, and Deduction, with all the various forms of the Syllogism, were the answer to these newly created demands. Aristotle's

logic did promote knowledge of the natural world *as it exists*. It gave no help in *changing* it.

A parallel development was made in psychology. As Matter and Form were no longer allowed separate existence in the universe at large, so, in the little world of man, body and soul were not allowed separate existence either. The soul was no longer looked upon as a stranger temporarily imprisoned in the body. Soul and body were two aspects of a living thing. The activity of the mind was not distinct from, or opposed to, the activity of the senses, but continuous with it, a part of the same living process. In his treatise *On the Soul* Aristotle analyses very penetratingly the physiological basis of the various movements of the soul – imagination, memory, dreaming, the passions. Mental processes become for him psycho-physical. This development should have carried with it the denial of the doctrine of the immortality of the soul. But here Aristotle exhibits a characteristic recoil. One activity of the soul remained for him purely psychical. The teaching of his *Metaphysics* and his *Logic* had vindicated the claim that there could be a true science of nature, that valid thinking was possible about things. But it was also possible to think about thought. Thought about thought had no material content, only a formal one. This, then, taught Aristotle, is the highest exercise of mind; man, in so far as he is capable of this exercise, may claim immortality. In thinking about thought the eternal part of man is concerned with the eternal. The part of the soul that thinks about thought cannot die. In a noble, and pathetic, sentence in his *Ethics* Aristotle admonishes mortal man to 'be as immortal as possible'. The phrase, at least, is immortal, as we mortals reckon immortality.

The effect of Aristotle's criticism of the Theory of Ideas was that he had again made possible a science of nature. By

refusing any separate existence to the Idea, by teaching that the Idea existed only as it was embodied in the material world, he had made the Idea capable of yielding knowledge of appearances. The task of the researcher became to find the Forms in the material world. This new conception of the relations of Being and Knowing provided the basis for the biological work which occupied the last twelve years of his life. He produced a great series of works – the most important are the *History of Animals*, *On the Parts of Animals*, *On the Generation of Animals* – based partly on second-hand information, partly on original research. He mentions some 500 different kinds of animals, he personally dissected some fifty different types. His newly created logic came into its own. The task of classifying the animal kingdom according to its genera and species was the task of finding the Forms in Matter. Biology was the pre-ordained field for the application of Aristotle's logic. Nobody was proposing to change plants or animals. His logic had no fruitful application to chemical practices.

In embarking on his biological researches Aristotle again reveals his awareness of the fact that he is departing from the tradition of the Academy which he had followed so closely in his Physical treatises. He feels the need of defending his innovation, but his defence is now confident and firm in tone. 'Natural objects,' he writes, 'fall into two great classes, the immortal ones that are without beginning or end, and those that are subject to generation and decay. The former are worthy of honour, for they are divine, but they are less within the reach of our observation. All our speculations about them and our aspirations after knowledge of them can only in the rarest instances be confirmed by direct perception. But when we turn to the plants and animals that perish, we find ourselves better able to come to a knowledge

of them, for we are inhabitants of the same earth. Anyone who is willing to take the necessary trouble can learn a great deal about all the species that exist. Both enquiries have their charm. In the case of the heavenly bodies we can achieve little owing to their being out of our reach, yet the veneration in which they are held imparts to our knowledge of them a degree of pleasure greater than appertains to any of the things that are within our reach, as a lover would rather catch a chance glimpse of his beloved than have a complete view of many other precious things. But terrestrial objects, owing to our better and fuller acquaintance with them, have the advantage from the scientific point of view. Indeed their nearness to us and their kinship with us may be said to counterbalance the claims of divine philosophy. And, as I have already expressed my views on the former subject, it remains for me to treat biology, omitting nothing so far as I can avoid it, however little or great be the honour in which it is held' (*The Parts of Animals* I, 5). This interesting passage, of which space alone prevents us from quoting more, confirms the view that the biological works are later than the physical and that they are the result of a new attitude to nature and to observation.

At the same time, in searching for the Forms in nature, Aristotle maintained the teleological method of interpretation, a method not in favour with most modern biologists. Aristotle had carefully distinguished the Formal from the Final cause. In fact the two concepts lie very close together. The Forms represent the intelligible side of nature, the design in nature. They also represent the active element. Matter is inert, passive. The Forms are active and compel nature to take their shape. The whole activity of nature consists in the bringing of order out of chaos by stamping Form on Matter. The Forms are, in short, merely an alias for Providence or

God. The Final is ultimately indistinguishable from the Formal cause. The old Socratic mode of explanation, that things are as they are because it is for the best that they should be so, reappears in a more sophisticated dress. An illustration of this point will be helpful. We shall choose one that will again bring to light the great divergence between the Ionian and the Socratic view of nature.

We have already referred to the opinion of Anaxagoras, that it was the possession of hands that had made man the most intelligent of the animals, an opinion itself dependent on an understanding of the rôle of techniques in the development of man. Let us now hear the argument by which Aristotle rejects this opinion. 'Man alone of all the animals is erect, because his nature and his substance are divine. To think, to exercise intelligence, is the characteristic of that which is most divine. This is not easy if much of the body is situated in the upper part. For weight renders the exercise of thought and perception sluggish. Accordingly, if the weight and the bodily element increase, bodies must bow down to earth; then, for security, nature must substitute fore-legs for hands and arms, and we get quadrupeds. ... But man being erect has no need of fore-legs; instead of them nature has given him hands and arms. Now Anaxagoras has said that it is the possession of hands that has made man the most intelligent of the animals. The probability is that it was because he was the most intelligent that he got hands. For hands are a tool, and nature, like an intelligent man, always distributes tools to those that can use them. The proper thing is to give a genuine flute-player a flute rather than to give a man who happens to have a flute the skill to play; for that is to add the lesser to the greater and more august instead of adding the greater and more precious to the lesser. If, then, it is best that it should be so, and if nature, out of what is possible,

always does the best, it is not because he has hands that man is wise, but because he is the wisest of the animals he has hands' (*Parts of Animals*, IV, 10). This is nothing but the *Timaeus* over again. It is astonishing to find this passage embedded in the biological works of the closing years of his life. Very probably it was written early. But there is no part of Aristotle's writings in which the outlook of the *Timaeus* may not recur.

This question of hands serves also to introduce our last topic. Following the subdivision we made in our chapter on Plato, we have now discussed Aristotle's attitude to astronomy, and to what the ancients called *physics*, and have found that here he achieves only a slight and hesitant advance on Plato. Secondly we have examined his attitude to observational research, and found that in his biological studies he makes an immense step forward. What was his attitude to our third topic, that of the rôle of techniques in the development of society and in supplying concepts for the interpretation of nature?

Our earliest, and in many ways our best, account of the pioneers of Greek science comes from Aristotle, from the first book of his *Metaphysics*, or *Theology*, as he himself called it. Here it is amusing to observe his anxiety to dissociate the origins of this branch of philosophy from production, from the techniques. 'That it is not a productive science is clear,' he writes, 'even from the consideration of the earliest philosophies. For men were first led to study philosophy, as indeed they are to-day, by wonder. At first they felt wonder about the more superficial problems; afterwards they advanced gradually by perplexing themselves over greater difficulties; e.g., the behaviour of the moon, the phenomena of the sun, and the origination of the universe. Now he who is perplexed and wonders believes himself to be ignorant. Hence even the lover of myths is, in a sense, a philosopher, for a myth is a

tissue of wonders. Thus if they took to philosophy to escape ignorance, it is patent that they were pursuing science for the sake of knowledge itself, and not for any utilitarian applications. This is confirmed by the course of the historical development itself. For nearly all the requisites both of comfort and social refinement had been secured before the quest for this form of enlightenment began. So it is clear that we do not seek it for the sake of any ulterior application. Just as we call a man free who exists for his own ends and not for those of another, so it is with this, which is the only free man's science: it alone of the sciences exists for its own sake.' His main point is clear. As a free man is to his slaves, so is philosophy to the practical sciences.

Again, in the same connection, he writes: 'It was natural that in the earliest times the inventor of any Art which goes beyond the common sense-perceptions of mankind should be universally admired, not merely for any utility to be found in his inventions, but for the wisdom by which he was distinguished from other men. But when a variety of arts had been invented, some of them being concerned with the necessities and others with the social refinements of life, the inventors of the latter were naturally always considered wiser than the former because their knowledge was not directed to immediate utility. Hence when everything of these kinds had been already provided, those sciences were discovered which deal neither with the necessities nor with the enjoyments of life, and this took place earliest in regions where men had leisure. This is why the mathematical arts were first put together in Egypt, for in that country the priestly caste were indulged with leisure.' Again the main point deserves emphasis. We owe the beginning of a true knowledge of reality to the leisured priests of Egypt, not to the technicians who found out how to do things.

The importance Aristotle attaches to this new leisure-class mode of thinking about nature, which he calls either First Philosophy or Theology, leads him, however, to some unhistorical judgments which contradict the opinions of older thinkers. (1) Aristotle asserts that the mathematical arts were first invented in Egypt because there the priests were indulged with leisure. The opinion of Herodotus (II, 109), universally accepted in modern times, is that geometry arose in Egypt owing to the necessity of resurveying the land after the inundations of the Nile. (2) Aristotle tells us that the inventors of the *refinements* of life were always considered wiser than the inventors of the *utilities* because their inventions were not useful. Plato makes it clear that the outlook of the Ionian thinkers was very different. He tells us that they regarded as the most important of the arts those that helped man by supplementing and imitating nature, like medicine and agriculture. (3) But the most arresting feature about the whole passage is this, that, in his concern to ascribe the origin of true Philosophy to the faculty of wonder in man, and not to utility, *Aristotle makes it clear that he regards applied science as something which has already completed its task.* Metaphysics is only possible because 'nearly all the requisites of comfort and social refinement have been secured', because 'everything of these kinds has already been provided'. The whole idea of a more effective exploitation of nature in the interests of mankind is dead for Aristotle. The fact that the comforts and refinements are available only for the few is not discussed. This outlook is reflected not only in his philosophical and scientific works, but informs the whole of his political philosophy, which is solely concerned with the management of men. The fundamental problem is that of securing a docile labouring class. He hopes for the disappearance of the free labourer and the universalization of the master-and-slave

relationship. This, he says, is what nature intends. It is only because nature is not 100% reliable that she does not produce two distinct physical types. When the statesman, instructed in the Aristotelian point of view, helps nature to realize her intention, when men really are unmistakably born Masters and Slaves, or divided by society into these two classes, the leisured class will be free for the noblest exercise of the intelligence, to wit, Metaphysics, First Philosophy, Theology. Thus, by virtue of the existence of the slave class, will the Master be enabled to fulfil the injunction to 'be as immortal as possible', to think about thought, not about things. Immortality itself becomes a class privilege.

The failure of Aristotle, the tutor of Alexander, to allow for further decisive progress in techniques, is a reflection of the general failure of the society of the age. Rostovtzeff, in his *Hellenistic World* (pp. 1166 ff.) discusses this phenomenon. He speaks of the failure to acclimatize plants and animals, the failure to use the Mesopotamian oilfields and the Dead-Sea bitumen, the absence of technical advances in agriculture and in metallurgy, the failure to devise any improvement in methods of extracting mineral ores other than forced labour in ever larger quantities, the arrest of the textile industry at a pre-Hellenistic level. It is a sad picture, but it is the precise counterpart of the teaching of the *Republic* and the *Laws* of Plato and of the *Metaphysics* of Aristotle. The arrest of Greek science is only one aspect of the arrest of Greek society.

CHAPTER NINE

Résumé and Conclusion

★

IN THE preceding chapters an effort has been made to think out afresh the meaning of the history of science in the ancient world, and especially in the formative period of Greek thought. The subject is difficult. Opinions on it differ. Our effort in this chapter will be to make as clear as we can what precisely are the lessons we see in it for the modern world.

In the first place, we claim that the human activity we call science did not originate as a mode of thinking about things in order to be able to give verbally satisfying answers on any question that may be raised, but as a mode of thinking about things so as to be able to manipulate them to desired ends. Scientific thought is distinguished from other modes of thought by being proved valid in action. Our opinion on this matter may be expressed in the words of a French writer whose work appears to have missed recognition in this country.

'At the same time as the religious idea,' writes Félix Sartiaux, 'but much more slowly, because it requires much greater effort, the idea of science separates itself out from the magico-mystical mentality of primitive man. By handling tools, by making objects for a predetermined end, man, in spite of his inclination to represent things in his own image, seizes distinctions, forms ideas of classes, observes relations which do not depend upon his imagination. He comes to see that things do not happen as the rites represent, that they do not behave in the manner of spirits. If he had kept to his

magico-religious and his religious dreams, he could never have *done* anything. But in fact, from remotest times he really kills animals and soon domesticates them, he cultivates plants, he extracts metals from ores, he makes objects for ends which he sets before himself. These actions, whatever be the representations which accompany them, succeed. Accordingly, consciously or not, man grasps true relations and submits himself to them. The existence of techniques, which go right back to the palaeolithic age, shows that there exist in the most primitive thought traces of the scientific spirit.'*

In the ancient civilizations of the Near East this scientific mode of thought hardly succeeded in extending itself beyond the sphere of the techniques themselves, but coexisted with a mythological interpretation of the universe. This mythological interpretation of the universe was developed and handed down in priestly corporations, and served very largely a political purpose. The technicians, whose practice contained the germ of science, were engaged in manipulating matter. The priests, on whose shoulders rested the maintenance of the social structure, were mainly occupied in controlling men. In particular the need to control men necessitated the maintenance of mythological interpretations of the major phenomena of nature – the motions of the heavenly bodies, the changes of the seasons, vegetation, irregularities or violences in nature.

The specific originality of the Ionian thinkers was that they applied to the interpretation of the motions of the heavenly bodies and all the major phenomena of nature modes of thought derived from their control of techniques. Fortunate political circumstances made it possible for them to do this. They represented a new element in society, a new class of manufacturers and merchants which brought a temporary

***Morale Kantienne et Morale Humaine*. Paris, 1917, p. 254.

peace and prosperity to communities worn out with the struggle between the landed aristocracy and dispossessed peasants. Being dominant in society, they made their mode of thought dominant. While feeling still secure in their possession of political power, they did not hesitate to ridicule the old mythological explanations of nature and attempt to substitute for them explanations of 'the things above' derived from their practical experience of 'the things below'.

The economic basis of this way of looking at the world was introduced into Attica at the beginning of the sixth century by Solon. Solon was a merchant who was called upon to rescue Athens from a desperate *impasse* into which it had fallen in the course of the usual struggle between the landlords and the peasants. He provided an economic alternative to the land by the introduction of the industrial techniques, and tried to secure that every Athenian should teach his son a trade. Athens was an industrial and trading town in the centre of an agricultural area when it became a democracy.

'It is interesting to note,' writes W. H. S. Jones, 'that the arts were distinguished from the sciences only when Greek thought was past its zenith.'* In the middle of the great fifth century, at the height of the Periclean Age, this distinction had not yet been made at Athens. This was the age when a working sculptor like Pheidias, or a working architect like Ictinus, were ornaments in the best society. This is the outlook which is reflected in the finest products of the literary art of the time.

Æschylus, for instance, writing just before the middle of the century, puts into the mouth of the fire-bringer Prometheus a splendidly imaginative account of the rôle of techniques in the development of human society. Man, he makes Prometheus say, was in the beginning as witless as a

*Hippocrates (Loeb Library), IV, p. xxiii.

babe. He had eyes but could not see, ears but could not hear, and lived in a dream-world of illusion, until Prometheus planted in him mind and the gift of understanding. In what did the gift of understanding consist? In this, that whereas man had before lived like an insect in sunless subterranean caves without knowledge of brick-making or carpentry, he now lived in well-built houses facing the sun. Previously he could not anticipate the coming of winter, spring or summer; now he had learned to read the stars, and had made himself a calendar. Previously he could neither reckon nor write; now he had a system of numerals and an alphabet. Previously he had had himself to toil as a beast of burden; now he had subdued wild animals to bear pack and harness. Previously he had not known how to cross the seas, cure himself when ill, or read the future; now he had linen sails, herbal remedies, and an art of divination. To crown all, he had brought up from their hiding place in earth those buried treasures, gold, silver, bronze, iron.* Such is the account of the growth of civilization given by Æschylus. Plainly for him the conquest of the techniques is identical with the growth of intelligence. The idea of a science except as applied does not occur to him.

A few years later Sophocles, in a famous chorus of his *Antigone* (332 ff.), again takes up the theme of the technical inventiveness of man. Wonders are many, he sings, but nothing is more wonderful than man. He is the power that crosses the white sea. He makes use of the storm-winds to bear him along under surges that threaten to engulf him. From year to year, the mule, the new strong animal he has bred from the horse, drags his ploughshares through the soil of Earth, oldest of the gods. In his toils, by his superior wit, he snares the birds, the beasts, the fishes of the deep. The shaggy-maned horse and the tireless mountain bull he tames

*Æschylus, *Prometheus Bound*, 436 ff.

and puts beneath the yoke. He has taught himself how to speak. He has taught himself how to think. He has taught himself the modes of civilized behaviour. He has made himself houses to escape the frost and the rain. For everything except death he has found a remedy. He can even cure disease. His technical ingenuity, though it brings him now to evil now to good, shows a wisdom which defies imagination.

These are but pedestrian paraphrases of the untranslatable poetry of these great tributes to the inventive genius of man, but they will serve to indicate their content. The list of man's achievements in Sophocles is much the same as that in Æschylus, but whereas the exigencies of his plot compel Æschylus to refer the invention of all the techniques to Prometheus, Sophocles openly states what, of course, Æschylus does not intend to deny, that all these are the achievements of man himself. Such, of course, was the opinion of their contemporary, the philosopher Anaxagoras, also a resident in Periclean Athens, who taught that it was through the possession of a capable pair of hands that man became wise.

In the wreck of the ancient literature it is not easy to illustrate as abundantly as one could wish the method of the philosopher-scientists who saw in the techniques the clue to the understanding of the operations of nature. One treatise, however, which we have examined at some length, stressed the contribution made by the cook to the understanding of human nature and of nature in general. And, amid numerous other examples, we have seen the attempt of Empedocles to throw light on the relation of the external atmosphere and the movement of the blood in the human body by an experiment with the water-clock. This experiment also established the conclusion that the fundamental operations of nature, the interaction between the elements, takes place on a level below the apprehension of our senses. It became a problem

for the scientist to infer the hidden operations from observation of the visible ones.

There is extant another Hippocratic writing* which shows us how one scientist attempted to put this method into use. The treatise seems to be the work of the director of a gymnasium who lived about the end of the fifth century. His belief was that human nature was a blend of fire and water. His difficulty was that these elements, on which depend the vital activities of man, are, in their ultimate nature, like the air investigated by Empedocles, too subtle for man to perceive directly. How does he get over his difficulty? From internal evidence it is clear that he was a student of Heraclitus, of Empedocles, of Anaxagoras, in whose thought about the universe we have found many traces of the influence of techniques. As these cosmologists had used ideas derived from techniques to explain the nature of the universe, so our physician turns to techniques for his explanation of the nature of man. He talks a lot of nonsense in doing so, as his predecessors who employed the same method also did. But the point we are concerned with for the moment is the method, not the results.

First he enunciates his general principle. The invisible processes of human nature, he says, may be observed by attending to the visible processes of the techniques. Men miss this point, for they do not understand that the technical processes they consciously control are imitations of unconscious processes in man. The mind of the gods, he explains, has taught men to copy in their arts the functions of their bodies. Men understand the arts (*i.e.*, employ them successfully), but they fail to understand what the arts are copies of. They should realise that the arts are a clue to the obscure operations of nature.

**Regimen* I, chapters xi–xxiv.

Here it is important to consider what the writer means by 'understanding'. He does not mean the ability to give a verbal explanation. He means the ability to act consciously to achieve a desired end. He wants to act upon the human body with a view to promoting and preserving its health. He thinks he can derive hints from the already established arts for the new art of health he is trying to create. The arts to which he directs attention are those of the seer, the blacksmith, the fuller, the cobbler, the carpenter, the builder, the musician, the cook, the currier, the basket-maker, the goldsmith, the statuary, the potter, the scribe. His master idea seems to be that, if we act rightly in regard to the visible aspect of things, the invisible processes we desire will inevitably follow.

It is in this sense that he sees an analogy between certain physiological processes and seercraft. The seer, by observing the visible, *i.e.*, present events, is able to foretell the invisible, *i.e.*, future events. So a man and a woman by a present act of intercourse begin the process which results in the future in the birth of a baby. In the same way, he implies, we may hope to discover the course of present action which will result in future health.

He tries to get closer to answering this question by consideration of the manufacture of iron tools. In his view of things man is a mixture of fire and water, but fire and water are also constituent elements of steel. The smith, by blowing fire on iron, takes 'nourishment' out of the iron, which becomes 'rare' and pliable. He then beats it, welds it, and tempers it with water. The tempering with water is a way of putting the nourishment back. The same happens to a man when he is trained. His breath fans the fire in him which consumes the nourishment. When he has been made 'rare' he is struck, rubbed, and purged. Then the application of water (*i.e.*, nourishment) makes him strong.

We shall not here follow out the analogies he draws between his regimen of health and the long list of other arts mentioned. They are fantastic enough, but it would be a mistake to regard them as devoid of all scientific value. Only those unfamiliar with the prodigious difficulty of the first steps in any science, and with the tentative and groping thoughts that accompany these steps, will fall into this error. Our author is proposing to *do* various things to men's bodies. His prescriptions of exercises, baths, massage, purgings, and dietings are far from useless. By comparison with other arts he tries to get a clearer understanding of what he is doing. But our main point here is not the value of the results but the nature of the method. The more fantastic the analogies between physiological processes and industrial techniques, the more significant is the fact that our author should have had recourse to this method. At a more primitive level he would have supposed the body to be the abode of spirits and would have prescribed accordingly. Now he thinks human physiology to be like the operations of the smith, cobbler, and potter, and prescribes accordingly. The primitive conception of nature has been transformed by the same force as had transformed primitive society itself, the practice of the techniques of production.

What was the special merit of this mode of explanation? What gave it its great importance in the history of science? When Plato came to the end of his knowledge in any direction he had recourse to a myth. Aristotle, in the same passage in his *Metaphysics* in which he claims that true science never had any connection with production, tells us that myth-making is a sort of science. It is unhappily true to say that the majority of historians of ancient thought still approve the practice of Plato and the opinion of Aristotle. On what grounds do we dissent? It is because the myth is subject to

no test and therefore cannot lead to knowledge. The ideas derived from consideration of the techniques, on the other hand, were continually tested in practice. It would, in fact, be fair to describe the Platonic myths, like their predecessors in Egypt and Babylon, as opinions about nature which have a value for the control of men. The opinions about nature derived from the techniques had a value for the control of matter. That is to say, they were science.

In the earlier period of Greek thought, then, when the sciences were not distinguished from the techniques, science was plainly a way of *doing* something. With Plato it became a way of *knowing*, which, in the absence of any practical test, meant only talking consistently. This new kind of 'science', like its predecessor the technical mode of explanation, resulted from a change in the character of society. Historians of society are still disputing the precise degree to which the industrial techniques had, by Plato's time, passed into the hands of slaves. For our purpose it is not necessary to give a more precise answer to this question than to say that for Plato, and for Aristotle, the normal and desirable thing was that the citizen should be exempted from the burden of manual work and even from direct control of the workers. The kind of science they aimed at creating was a science for citizens who would not directly engage in the operational control of the physical environment. Their modes of explanation necessarily excluded ideas derived from the techniques. Their science consisted in being able to give the right answers to any questions that might be asked. The rightness of the answer mainly depended on its logical consistency. This was not all loss. The enormous advances that were made in mathematics largely through the encouragement of Plato and the influence of the Academy transformed the conception of the universe. Whereas the Ionians had such incorrect ideas

of the sizes and distances of the heavenly bodies that their astronomy is not to be distinguished from meteorology, the mathematicians soon began to make it clear that our world is but a speck in a vast universe of space. Again, the Ionians, fertile in ideas, had but little developed the capacity to analyse their logical implications. A page of good Aristotelian logic can make their world of discourse seem as primitive as the mathematicians made their world of sun, moon, and stars. But, in spite of these advances in mathematics and logic, the separation of science from the fertilizing and controlling contact with techniques dealt it a crippling blow from which throughout the whole period of antiquity and the Middle Ages it failed to recover.

The new conception of science which came in with Plato and Aristotle demonstrably had its origin in the new form of society which rested on the division between citizen and slave. There is no aspect of Plato's thought which does not reflect a fundamental dichotomy derived from this division in society. In the developed theory of slavery the slave was not regarded as a rational being. The master alone was capable of reason, the slave might hold 'correct opinion' if he strictly followed the directions of his master. This master-and-slave relation became fundamental for Plato's thought in every sphere.

First the political sphere. Here Plato conceives of the relation of ruler and ruled in terms of master and slave. He intends government to be for the good of the governed, but it does not require their consent. His golden men, the fully enlightened aristocrats who are to rule, are a small minority of the population. All the rest are in some degree slaves, whose only chance of doing good is to obey mechanically the commands of their superiors. The manual labourer if left to himself could not rule himself, he would be ruled by his appetites. Plato oddly conceived the main activities of the

worker to be concentrated, not in his hands, but in his belly and his loins. Artisans are to stand to philosophers in the relation of slaves to masters. There is no difference between the art of the slave-owner and that of the king except the size of their respective establishments. This is the doctrine Plato preached in the city the basis of whose democratic life had been the implanting of the arts by Solon.

Plato's psychology, physiology, and ethics are all three made to conform to this master plan. In the State Plato had conceived of three classes – the Rulers, their Auxiliaries (the soldiers and police) and the Producers. The introduction of a third class does not involve any fundamental departure from the master-and-slave relationship, for the main function of the Auxiliaries is to secure the control of the Producers by the Rulers. On this analogy the soul is made to consist of three parts, the reason, the spirit, and the appetites – the reason corresponding to the rulers, the spirit to the police, and the appetite to the workers. Here we perceive the *social* significance of the rejection of the view of Anaxagoras, that the hand had been the chief instrument in the creation of intelligence. The workers are not embodiments of manual skill, but of *appetite*. Compare Plato with Æschylus and Sophocles and realise the greatness of the change.

The physiological counterpart of this class-psychology is worked out in detail in the *Timaeus*. The head is separated from the trunk by the neck, because the divine part of the soul, which is located in the head, must be saved from pollution by the mortal part, which is situated in the trunk. Then the trunk itself is divided by the diaphragm, so that the womanish and servile elements in the soul may be lodged apart in the lower chamber, while the manly and spirited element is lodged above, 'within earshot', as he says, 'of the discourse' of reason which goes on in the head, so that it may

combine with reason in suppressing any rebellion of the appetites. The ethical system which flowed from this psychology was harsh and puritanical. There is a sharp cleavage between soul and body. Soul stands to body in the relation of master to slave. The notion that the bodily sensations of pleasure and pain should be attended to by the mind as a basis for ethical action is viewed with the same suspicion as the political proposal that the mob should have a voice in the making of the laws.

To his interpretation of the system of the universe the same key was applied. Mind and matter stand opposed to one another as master and slave. If there is any regularity or beauty in Nature, it is because mind imposes order on matter, which is essentially disorderly. It follows that reason, not sense-evidence, is the true path to science. Reason brings us directly into contact with the mind which imposes order on matter. In the *phenomenal* world, with which the senses hold converse, this order is but imperfectly achieved.

This new view of the relation of mind and matter implies a radical departure from the first premiss of the older school of natural philosophers. The older view had been that there is a necessary order in the material world, and that the human mind grasps truth in so far as it grasps this necessary order. This order could only be apprehended by sense-evidence. To the interpretation of this evidence human experience in the exercise of techniques lent the necessary clue. For Plato, however, true science is teleological. It consists in interpreting phenomena in the light of the ends at which the Mind which strives to direct all things is presumed to aim. These ends are discovered, not by observation, but by reason. Not by trying to act upon nature but by argument about ends will the truth be discovered.

This strange new view of matter as a principle of disorder

underlies also the philosophy of Aristotle. 'Matter is made responsible for most irregularities,' as one of the latest puzzled enquirers puts it,* noting at the same time that this involves a radical departure from the Ionian point of view. To the puzzle which he raises this enquirer can give no answer, nor is he likely to be able to do so while he continues to look in the wrong place. The clue to Aristotle's strange view of matter is not to be found in his physical treatises but in his *Politics*. As with Plato, the master-and-slave relation provides the basic pattern for his thought in every sphere.

Aristotle, as is well known, was a defender of slavery on the ground that slavery is natural. By calling it natural he meant, as a recent authority has reminded us, that 'it follows a pattern that pervades all nature'.† In Aristotle's own words: 'In every composite thing, there is always found a ruling and a subject factor, and this characteristic of living things is present in them as an outcome of the whole of nature.'‡ One must not be put off here by the bad logic. It is difficult to suppose that Aristotle really regarded master and slave as forming a 'composite thing'. But all the logic of Aristotle's justification of slavery is bad. As Montesquieu long ago observed, 'Aristotle undertakes to prove that slavery is natural and what he says does not prove it'. What concerns us now is not his attempted justification of slavery, but the effect of the attempted justification on his science. Seeing the master-and-slave relation as a pattern that pervades all nature, he regards matter as being refractory, disorderly and

*D. M. Balme, *Greek Science and Mechanism*, Cl. Q. xxxiii, p. 132.

†Gregory Vlastos, "Slavery in Plato's Thought." *Philosophical Review*, May, 1941. This very valuable paper gives the references to Plato's text on which the argument of the preceding paragraphs rests.

‡*Politics*, 1254a.

resistant, and Nature, or Mind, as imposing on matter the working out of definite ends. The attributes which Aristotle applies to matter are puzzling until one understands that they are the same attributes as he applies to the slave.

His famous fourfold theory of causation derives from this conception of the relation of Nature to matter. According to Aristotle, the earlier thinkers, the Ionian natural philosophers, had considered only the material cause and constituted thereby only a primitive, 'stammering' kind of science. This was all that could be expected since they considered only the subject, slavish element in any product of Nature. Aristotle himself proposes to add three additional types of cause, the Efficient, the Formal, and the Final. These are the types of cause which explain how Nature imposes ends on refractory matter. This is Aristotle's dominant conception of science – the understanding of the way in which Nature, which resembles a Master in having ends at which it aims, imposes its will on matter, which sometimes resists those ends, and, like the slave, can achieve nothing except under the direction of a superior will. He even goes so far as to claim that the difficulty in distinguishing a natural slave from a natural master is due to a failure of Nature to impose her will on matter. Nature intends, he says, to produce a type of man who will be immediately recognisable as devoid of reason, 'a living implement', but fails to do so because matter is refractory. Part of his art of politics is designed to make good this failure of Nature. When men are natural slaves and do not know it, it is, he says, the business of the natural masters to bring it home to them.

In an earlier chapter we saw how the importation of ideas from the politico-religious sphere had affected the development of astronomy. Here we have a further illustration of the same point. The older Ionian conception of an objective

order in Nature had been derived from the necessity of conforming oneself to the regular behaviour of matter if one was to be successful in the performance of technical processes. It was not the orderly motion of the heavenly bodies that gave man his first idea of regularity in nature, but the experience, endlessly repeated, that things have their own ways of behaving – that you cannot gather figs of thistles, nor make the hardest bronze unless you put one portion of tin to ten of copper, nor get the octave higher unless you halve the string. The conception of nature as infinitely various and ingenious but inexorable in its laws is the conception of technicians who attempt to exercise over matter an operational control. The new conception of Nature, as a power with ends in view, which enforces its will on a subordinate but refractory matter, is the conception of a master who governs slaves.

'The political aspect of the Greek philosopher's reality is the most fundamental, and in it, if anywhere, will be found the clue to his more abstract ideas,' observes a recent writer.* This statement contains an important truth, but it is not the whole truth. In the period of philosophy we have rapidly passed under review, that from Thales to Aristotle, it has been universally recognised from antiquity down that there is a double tradition, roughly defined as the religious and the scientific. The true nature of the distinction, however, has not always been perceived. In the scientific tradition, in spite of all the unfounded speculation in which it is involved, there is a genuine core of observation confirmed by practice which is its distinctive quality. It is in the other tradition, generally called the religious, but which would be better designated the politico-religious, that an order of ideas derived from the structure of society is dominant. This order of ideas is not

*J. S. Morrison, "The Place of Protagoras in Athenian Public Life," *Class. Q.*, xxxv, p. 1.

worthy of the name of science because it involves little, if any, element of observation and is wholly removed from the possibility of being tested in action. To this order of ideas belongs the theological astronomy of Pythagoras, Plato, and Aristotle. To this order of ideas must also be relegated the Platonic and Aristotelian conception of matter as a principle of disorder and irregularity, and of true science as the explanation of Nature in terms of the ends at which she is presumed to aim. Theological astronomy and teleological physics are corruptions of science induced by political exigencies – the problem of controlling the mob and the problem of controlling the slave. 'It is wrong to confuse natural philosophy with law-making,' drily remarks Epicurus in a passage in which he rejects the theological astronomy of Plato and neatly indicates the source of its weakness.

We have now completed our brief survey. We set ourselves a limited objective, and are all too painfully aware how imperfectly we have attained it. We have passed in review the contributions to science of a number of outstanding men: Thales, Anaximander, Anaximenes, Heraclitus, Pythagoras, Parmenides, Empedocles, Anaxagoras, Democritus, Socrates, Plato, Aristotle, not to mention the nameless contributors to the Hippocratic corpus. The fascination of their thoughts has not been weakened by the passage of time. But our purpose has not been achieved, nor the meaning for us of Greek science revealed, unless we have also brought to light what historians have too little considered, the intimate connection between the development of that body of theory and that practical activity we call science and the total life of the society in which it takes shape. Better histories of Greek science will soon be written than the world has yet seen. But the necessary pre-requisite is the acquisition of a better knowledge of the technical history of Classical antiquity and

of its interaction with the total life of the time. The understanding of Greek science is not going to be advanced if historians, instead of revealing the historical genesis of the theories of the Greeks, spend their energies wondering whether the Greeks, by some extraordinary gift of speculative genius, had not been able to leap the centuries and anticipate the findings of modern science. If Aristotle, for instance, talks of the irregular behaviour of matter, it is not wise to attempt to explain this by suggesting that he had anticipated the modern theory of indeterminacy. Better explanations lie nearer to hand. The history of science must be really historical.

BIBLIOGRAPHICAL NOTE

1. Ancient Writers. The fragmentary remains of the Greek thinkers from Thales to Democritus can best be studied in Hermann Diels, *Die Fragmente der Vorsokratiker* (5th ed. by Walther Kranz, 1934). Two recent works by Kathleen Freeman, *Companion to the Pre-Socratic Philosophers* and *Ancilla to the Pre-Socratic Philosophers* (Basil Blackwell, Oxford), now offer the English reader a scholarly and full account of all the pre-Socratics and an extensive collection of their remains in translation. Burnet's *Early Greek Philosophy*, a standard work, should also be consulted. For the writings which survive in their entirety readers are referred to the various volumes of the Loeb Classical Library (Heinemann, London).

2. Modern Writers. To the references given in the text I wish to add two: – (*a*) Harold Cherniss, *Aristotle's Criticism of Presocratic Philosophy* (Johns Hopkins Press, 1935), and (*b*) Rudolfo Mondolfo's *Sugestiones de la Tecnica en las Concepciones de los Naturalistas Presocraticos* (*Archeion*, Nueva Serie T. ii. Vol. xxiii, N. i.). The first of these writers illustrates with an overwhelming display of proof the *fact* of Aristotle's failure to give a true report of the teaching of the Presocratics. The *reason* for this failure is better explained by Mondolfo. It is that the writings of the older thinkers were packed with references to techniques which, in a changed society, seemed beneath the dignity of philosophy.

B. F.

INDEX

By the same author

GREEK SCIENCE

VOLUME II — THEOPHRASTUS TO GALEN

A192

This second volume describes how after Aristotle, Greek Science, despite some exciting achievements by his immediate successors Theophrastus and Strato, went into a decline parallel to that which beset Greek civilisation as a whole. Yet when modern science began to show signs of life in the sixteenth century its pioneers were convinced that they were resuming the Greek tradition of a thousand years before.

'Their new science,' says Professor Farrington, 'was, in their eyes, a continuation of Greek science. The old Greek books which the invention of printing and the birth of modern scholarship were putting into their hands, were the best available, were, in fact, the most up-to-date books in various departments of knowledge. For Vesalius and Stevin in the sixteenth century the works of Galen and Archimedes were not historical curiosities. They were the best anatomical and mechanical treatises in existence. Even in the eighteenth century for Ramazzini, the founder of industrial medicine, Hippocratic medicine was still a living tradition, just as for Vico, the most profoundly original of all sociologists before Marx, Lucretius, with his Epicurean philosophy, could supply a basis for the new science of society. In one striking example the validity of a Greek text-book remained virtually unchallenged till our own century. A generation ago Euclid and geometry were still synonymous terms in English schools.

'Why did Greek science die if it had still such vitality that it was capable of a second birth? This death and rebirth, or sleep and reawakening, constitute our problem. In the attempt at a solution of this problem we shall find the meaning for us of Greek science. Accordingly, after our journey from Athens via Alexandria to Rome, we shall ask why science, which had folded its hands for sleep, sprang to life again in the Low Countries, in Germany, in Italy, in France, in England.'

THE WORLD'S WEALTH - *W. G. Moore.* A173

'An introduction for the layman to the subject of the location, production and distribution of the world's wealth, and a discussion of the factors that influence the last two processes and the economic problems connected with them.' - *The Times Literary Supplement.*

SCIENTIST IN RUSSIA - *Eric Ashby.* A186

The writer, a scientist attached to the Australian legation at Moscow for twelve months, gives a detailed account of education, especially of university life, in the U.S.S.R., and of the organisation of scientific research and enquiry, which will be of the greatest interest to all educationalists and social students.

RELIGION AND THE RISE OF CAPITALISM - *R. H. Tawney.* A23, 4th Impression

A study of religious thought on social issues during the three centuries from the later middle ages to the early eighteenth century.

THE BLEAK AGE - *J. L. and Barbara Hammond.* A171

This study of the first half of the nineteenth century is one which should be read by all who wish to understand the root causes of our social troubles, and so be the better able to judge the many remedies that are to-day being put forward for the future ordering of this country.

MATHEMATICIAN'S DELIGHT – *W. W. Sawyer.* A121

This is the third large edition of a volume specially written for the Pelican series in 1943. It is designed to convince the general reader that mathematics is not a forbidding science but an attractive mental exercise. Its success in this intention is confirmed by some of the reviews it evoked on its first appearance:

'May be recommended with confidence for the light it throws upon the discovery and application of many common mathematical operations.' – *Times Literary Supplement.*

GEOLOGY AND SCENERY IN ENGLAND AND WALES – *A. E. Trueman.* A185

This is a manual of landscape-recognition. The author shows how scenery is accounted for by certain specific facts of geology, and how the typical landscapes of, say, the Lake District or the Cotswolds owe their differences from each other to the age-long processes of geological formation.

'Contrives to be friendly, almost intimate. ... It has the marks of a classic' was the way it was described when it first appeared 10 years ago under the title of *The Scenery of England and Wales.*

THE INVENTOR AND HIS WORLD – *H. Stafford Hatfield.* A178

The present crisis in our affairs and the perpetual cry that we must export or die has riveted attention on the necessity of inventing new methods of production, of perfecting our manufacturing plants, and sometimes evolving entirely new gadgets and processes altogether. This also means a new approach to the problems of the inventor. The author, himself a back-room boy at the Admiralty, discusses not only the difficulties that face the inventor, but what is equally important his place in society.

THE POPULATION OF BRITAIN – *Eva Hubback.* A174

The problem of population so often raises in people's minds an impression of statistics both boring and confusing, that it is at once stimulating and encouraging to find that this subject can be made intensely interesting. This question is after all the most vital that affects everyone. Mrs Hubback, who herself has had long experience in social work and civic administration, here discusses the various facets of this problem, its relation to the past, how it has conditioned our present, and most important of all, how it will affect our future.

GENETICS – *H. Kalmus.* A179

Genetics, the story of heredity and variation, youngest of the biological sciences, is to-day exciting more attention than any other branch of biological enquiry. Dr Kalmus, lecturer in eugenics, biometry and genetics at University College, London, explains clearly the various factors of biological make-up in plants, animals and man, the importance of genetical knowledge to gardeners, farmers, and stock breeders and, not least, the human parent. The text is supplemented and explained by a number of simple diagrams.

THE SIZE OF THE UNIVERSE – *F. J. Hargreaves.* A193

This book is not a complete study of astronomy. It is an introduction to this lesser known but absorbing science made plain enough for the ordinary reader. The author has reduced to a minimum his use of scientific and technical terminology. The many illustrations and diagrams which figure in this book serve to emphasise the points he wants to make. The aim has been to bridge the gap between layman and astronomer.

THE SCIENTIFIC ATTITUDE

C. H. Waddington

A84

This is a revised edition of a book specially written for the Pelican Series. Published for the first time in 1941, it was considered appropriately topical, but the arguments which it puts forward apply even more forcibly in the post-war world of to-day.

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1/6

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